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Joseph Channing Pearce, Esq., M.B., The Manor House, Brixton Rise, S.W.; H. George Fordham, Esq., University Hall, Gordon Square, W.C.; and Richard Dickson Poppleton, Esq., Lesney Villa, Erith, Kent, were elected Fellows of the Society.

The following communication was read:—

The Secondary Rocks *of* Scotland. By John W. Judd, Esq., F.G.S. First Paper. *With a* Note *on some* Brachiopoda, by Thomas Davidson, Esq., F.R.S., F.G.S.

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General Introduction.

The Highlands of Scotland have long been recognized as an unrivalled field of study for the physical geologist; but to the stratigraphical geologist and the palæontologist, who seek for evidence to aid them in reconstructing the geographical features and determining the biological characteristics of successive geological periods, they have, till of late years, been regarded as comparatively barren of interest. An exception to this general statement must be made, however, in favour of the Old Red Sandstone of the district, which has yielded such admirable results to the studies of Murchison, Sedgwick, Malcolmson, Hugh Miller, Agassiz, and others.

Charles Peach's discovery in 1854 of Silurian fossils in Sutherland has already borne the most important fruit, and, in the hands of Murchison, Ramsay, Geikie, Harkness, and Jamieson, has afforded the necessary clue for determining the age of the great *Primary* masses of the Highlands.

Similarly the discovery by the Duke of Argyll of Miocene vegetation in beds intercalated with the basalts of Mull has been the starting-point in elucidating the history of the *Tertiary* period in the Highlands. Professor Geikie has already laid before this Society the first of a series of papers in which he proposes to treat this interesting subject.

The *Secondary* strata of the same area were, at so early a period as 1826, made the object of an admirable general survey by the late Sir Roderick Murchison; but the progress of geological science

since that date appears to create a demand, and at the same time to afford the necessary means, for a fuller and more minute investigation of the subject.

The isolated rock-masses of Secondary age which occur in th Highlands and Western Isles of Scotland, must ever be objects of the highest interest to geologists. They are evidently the vestiges of formations once widely spread, and have escaped the extensive denudation which has to such an enormous extent destroyed the contemporary and even older deposits of the district. Preserved to our study by accidents of the most striking character, they are now found in very unexpected situations, lying in the midst of the Older Palæozoic and often highly metamorphic rocks. On the eastern coast, as we shall see in the sequel, faults of enormous magnitude have let down these patches of Mesozoic strata among the older formations; while on the western coast the fragments of Secondary age which had escaped the enormous denudations of the Middle Cretaceous and Older Tertiary eras, were subsequently sealed up and preserved under thousands of feet of volcanic rocks, by the wearing away of which, at a period geologically recent, they have been at a few points exposed to our observation.

These fragments of Mesozoic strata, the true nature of which was first recognized by Macculloch, Buckland, and Lyell, were in 1826–7 made the subject of careful study by the late Sir Roderick Murchison. Rightly perceiving that the nearest analogues of these rocks would be found, not in the contemporary purely marine deposits of the south of England, but among the estuarine strata of Oolitic age in Yorkshire, that distinguished geologist prudently prefaced his work by a careful study of the latter under the able guidance of William Smith and John Phillips.

If the analogies of the Scotch with the Yorkshire strata were allowed too great weight, and, owing to the difficulties of the investigation at a time when our science (and especially the palæontological department of it) was still in its infancy, incorrect conclusions as to the exact age of many of these deposits were arrived at, every investigator of the subject will nevertheless gladly acknowledge the great value of this pioneer work of the master hand whose loss we still mourn. On every page of his memoir we recognize those powers of acute observation, of clear description, and of happy generalization which characterized the geologist who afterwards from the chaos of Transition and Grauwacke evolved the order of Siluria.

Since the date of those early researches Geology has made the most prodigious strides; and in no department have its advances been more rapid, and the results obtained more important, than in that which relates to the study of the Jurassic rocks. The direction and tendency of modern discovery and research have been such as to invest the outlying and fragmentary Jurassic deposits of Scotland with a new and deeper interest, and to call for their examination from a fresh point of view.

By the comparison of the persevering and minute researches of

indefatigable observers at many points, we are now able to perceive that the districts at present constituting England, Northern France, and Western Germany were included during the Jurassic and Neocomian periods within a single marine province, the very uniform succession of life in which has been clearly traced. Thus a palæontological scale has been constructed which, with due precautions, may be safely used for the determination of the age of any isolated rock-masses which were deposited within the limits of this old marine province. Further, the relations of the different strata and the conditions under which they were deposited at various points have been so far investigated that some progress has been made in determining the boundaries of the several gulfs, channels, and islands of that great sea and archipelago which constituted this life-province. This, in turn, has led to the recognition and study of the minor palæontological features which characterized the several subdivisions of that sea, and, in a much less degree (owing to the paucity of the evidence), of the several land-areas which bounded them.

Lastly, a considerable amount of knowledge has been gained of the succession of the movements of upheaval and subsidence by which the boundaries of the sea and land within this area were at different periods modified.

To the interesting patches of Jurassic strata in the Highlands of Scotland, then, we resort, and, in spite of the fragmentary character of the evidence in many instances, seek in them for the solution of many problems of the highest geological interest, among which we may especially instance the following:—

(1) The determination of the northern limits of the old life-province to which we have referred, and the question whether the Scotch deposits were formed within it.

(2) The special palæontological features of the province or subdivision of a province to which these strata belong.

(3) The conditions under which the various beds constituting the Mesozoic series in Scotland were deposited.

(4) The influence of climate in affecting the modes of deposition, and consequent character, of the rocks, and also in modifying the palæontological features of the area.

(5) The position and extent, with the nature and productions, of the lands bounding this portion of the old Mesozoic sea.

(6) The character and succession of the subterranean movements which affected the area during the Jurassic and subsequent epochs.

On each of these problems the study of the Highland strata throws important light; and to some of them it affords satisfactory and complete solutions. That in a case like the present, where the rocks preserved and exposed are of such a fragmentary character, some unfortunate gaps in the evidence will have to be lamented, is of course no more than might be anticipated; yet I hope to be able to show in the sequel that, by a careful examination, with the aid of the palæontological key, of every trace of these rocks left to us, the cases of total hiatus in the evidence are reduced to a remarkably small number, and that we are, in fact, able to sketch with

great completeness the history of the Jurassic system in Scotland, and to furnish many details with regard to that of the Triassic and Cretaceous.

I. *General Characters of the Jurassic Strata of Scotland.*

When we compare the Jurassic series as displayed in Scotland with that of the typical district of the south of England, we find many differences of a very striking and highly suggestive character. In the latter area the whole series, from the base of the Lower Lias to near the top of the Upper Oolite, is represented by strata which, while exhibiting evidence of having been deposited under very various conditions, determined by depth of water, distance from the shore, and nature of sediment, are yet all of undoubted *marine* origin. It is only at the commencement of this great period, in the Rhætic, and towards its close, in the Portland and Purbeck strata, that we find evidence of the *estuarine* conditions which afterwards prevailed during the deposition of the Anglo-French Wealden far into the Neocomian period.

As we proceed northwards into the Midland district of England, the Jurassic system begins to exhibit several intercalated series of beds with estuarine characters; but these, though of great interest in themselves, are nevertheless, as compared with the great mass of marine strata with which they are associated, subordinate in character and insignificant in extent.

In Yorkshire, however, there is evidence that, during the whole period of the Lower Oolite, estuarine conditions prevailed over a considerable area, and a series of strata was deposited consisting of sandstones, shales, ironstones, and thin seams of coal, which attains to a thickness of about a thousand feet; the marine beds associated with these are of a subordinate and local character. The other Jurassic strata in Yorkshire are of purely marine origin.

In Scotland, as I shall show in the present memoir, this gradual change of character in the Jurassic system as we go northwards, is carried still further. I shall have to describe the occurrence there, from the base of the Lower Lias up to and including the Upper Oolite, of a number of series of beds exhibiting estuarine characters. These alternate with marine strata, which, however, are often of very subordinate character and limited thickness. As is usually the case with strata deposited under these conditions, the succession of beds is found to undergo great changes within comparatively short distances; and thus the sections, at points not very remote from one another, often exhibit very remarkable contrasts. In some places the strata of estuarine origin are found to greatly exceed in thickness those of marine character, while in others the former are subordinate to the latter.

This gradual change in character of the Jurassic series, as we pass from south to north, finds a singular parallel in the Carboniferous system. There, as is so well known, the marked distinction between the marine strata of the Mountain-limestone at the base,

and the estuarine Coal-measures above, which characterizes the south of England, is gradually lost in going northwards,—beds of estuarine character gradually descending lower in the series in Yorkshire, as first shown by Professor Phillips, still lower in Northumberland, as described by Mr. G. Tate; while in Scotland, as has been illustrated by Professor Geikie and other writers, the whole Carboniferous series from top to bottom consists of estuarine strata with subordinate marine beds intercalated.

The estuarine strata of Jurassic age in Scotland exhibit two different types of petrological character, which, though occasionally passing into one another by insensible gradations, are usually very distinct and easily recognizable. These we may distinguish as the argillaceous and arenaceous types. The fossils of these estuarine strata usually afford us comparatively little aid in determining the age of the several series: our knowledge of the succession of forms among the freshwater mollusca is far too limited for us to obtain much aid from this source; and the few marine bands intercalated contain, as a rule, only specimens evidently dwarfed from unfavourable conditions, and scarcely ever belonging to highly characteristic forms like the Cephalopods and Echinoderms. The groups of marine strata, however, which alternate with the estuarine yield very fine and satisfactory faunas, by the study of which we are able to fix with great precision the limits of age of the latter.

The *arenaceous* type of the estuarine strata is characterized by beds of sandstone and grit, occasionally passing into conglomerates, and becoming in places somewhat calcareous. These alternate in some cases with subordinate beds of shale, and occasionally contain thin and imperfect seams of coal. The sandstone strata, which often attain to a great thickness, usually exhibit evidence of having been deposited under comparatively shallow-water conditions: false-bedding abounds; surfaces with ripple-marks, worm-tracks, and other indications of the proximity of the shore frequently occur; and the rock is usually crowded with fragments of carbonaceous matter. Large masses of wood, sometimes preserved as jet, and at other times presenting only hollow casts, abound in these sandstones; and occasionally vertical plant-markings, like those of the Lower Oolite in England, are also found. Not unfrequently we observe a rock made up of alternations of laminæ of sand and carbonaceous matter, so exactly resembling the strata seen in sections of old sand dunes, as strongly to suggest a similarity of origin. In all these sandstone strata molluscan remains are usually extremely rare; but occasionally bands of obscure shells, almost always in the form of casts, are found; these sometimes belong to marine, and at other times to freshwater genera.

The general resemblance of all these strata of the arenaceous type to those of the Lower Oolites of the Yorkshire coast is very striking; and it was not unnatural that, at the early date at which they were first studied by Sir Roderick Murchison, this should be accepted as evidence of identity of age. Hence the whole of these

strata have been hitherto regarded as contemporaneous with the Lower Oolites of Yorkshire. I shall, however, be able to show, from the manner in which the various series of estuarine beds, both on the east and west coasts of Scotland, alternate with marine strata, of which we are able to fix the age by the most conclusive palæontological evidence, that the former belong to various periods, from the Lower Lias up to the Upper Oolite.

The *argillaceous* type of estuarine strata, though usually forming series of much less thickness than those of the arenaceous type, presents many features of great interest. It is characterized by finely laminated clays, usually of green, blue, grey, and black colours, sometimes more or less sandy, and passing into fire-clay, and containing impure argillaceous ironstone in bands and nodules. These laminated clays contain also thin bands of limestone, sometimes crowded with shells of *Cyrena*, *Unio*, and other freshwater bivalves, sometimes with *Paludina* and other freshwater univalves, and at others made up of dwarfed *Ostreæ* and other marine shells, crowded together in masses, and forming beds exactly resembling the well-known "Cinder-beds" of the Purbeck. As in that formation, too, we frequently find thin seams of fibrous carbonate of lime, so well known to the workmen under the name of "beef-" and "bacon-beds." In these clays beds crowded with the valves of *Cyprides* and *Estheriæ* also occur, with veritable bone-bands, made up of scales and teeth of fish and bones of reptiles. Not unfrequently these clays are crowded with plant-remains; and interstratified with them occur beds of lignite or coal, sometimes several feet in thickness, some of which have been worked with success.

No one can examine these strata of the argillaceous type without being at once struck with their resemblance to those of the Purbeck formation, and also to those of similar character which occur at the top of the Wealden in the Isle of Wight and elsewhere, which I have described in detail under the name of the Punfield Formation. As the general similarity in character of the strata of the arenaceous type to the Lower Oolites of Yorkshire has led to their being indiscriminately referred to that age, so the peculiar characters of the strata of the argillaceous type have at various times led to the announcement of the discovery of Wealden, Purbeck, and Rhætic strata in Scotland. These strata, however, will be shown to belong to various portions of the Jurassic period; beds of precisely similar character occur in the Lower Oolites of the Midland district of England.

Nowhere is the fallacy of inferring the contemporaneity of deposits from the similarity of mineral composition so strikingly illustrated as in the Jurassic strata of Scotland. While from such resemblances in general characters, when due allowance has been made for metamorphism subsequent to deposition, we may usually safely conclude the conditions under which the two series were respectively formed to have been similar, yet to base any argument on them as to age can scarcely fail, as in the present instance, to lead to the most serious errors.

The marine strata associated with the various groups of estuarine beds in the Scotch Jurassic system also exhibit many very interesting characters. As compared with their equivalents in England, they usually show indications of having been of more shallow-water origin, and accumulated under conditions of a much more local character. While on the one hand there is a general absence of the thick masses of clays, formed of fine sediment and crowded with pelagic forms of life, like large portions of the Lias, and the Oxford and Kimmeridge clays, we find in many parts of the series great accumulations of conglomerate made up of the local rocks. At the same time there are not wanting proofs that, during certain portions of the Jurassic period, marine conditions prevailed over a very considerable area; and it is in these that the strata are found to assume the comparatively deeper-water and more normal characters.

The remarkable feature of the frequent recurrence of estuarine strata, though *characteristic* of the Scottish Jurassic series, is not *peculiar* to it. In the southern province of Sweden (Scania) we find a precisely similar set of phenomena to those which we have been noticing as so strikingly displayed in Scotland.

In Sweden the Secondary strata are exposed under the same disadvantageous conditions as in Scotland. Almost everywhere the surface of the country is concealed by great masses of drift of various kinds, above which a few hard ridges of Mesozoic rocks rise in isolated patches. Some of these patches are composed of Chalk and Upper Greensand; others of Jurassic strata presenting very peculiar characters. The exact geological relations of these singular fragments of Secondary strata have not apparently been fully determined, but, like the similar beds of Scotland, they are developed in the immediate vicinity of great masses of Silurian and granitic rocks. The Jurassic strata of Sweden consist of alternations of sandstones, shales, grits, quartzose conglomerates, impure lignites, and workable seams of coal: in some places these beds yield a beautiful flora; in others they contain bands with marine shells. These strata have been studied by Wahlenberg, Nilsson, Hisinger, Murchison, Braun, and others: and by some authors, as Brongniart and Mantell, they have been regarded (as were the estuarine Jurassic beds of Scotland) as representing the Wealden.

The two most important patches of these strata, those of Högonäs and Hör, have lately been made the object of careful and exact study by M. Hébert, who has shown that the marine strata at the base of the former contain a fauna which enables us to assign them to the base of the Lower Lias, while the evidence with regard to the latter, though less decisive, is such as to lead us to consider them to be of nearly the same age *.

Thus we see that there are reasons for believing that over a vast area, comprising the northern limits of the Anglo-Parisian basin, a

* "Recherches sur l'âge des grès combustibles d'Helsingbord et d'Högonäs (Suède méridionale), par M. Hébert," Annales des Sciences géologiques, tom. i. p. 117; Bull. de la Soc. Géol. de France, 2e série, tom. xxvi. (1870) p. 366.

similar set of conditions prevailed at the Jurassic epoch, marked by the deposition of strata of an estuarine character throughout the whole period. I need here only point out how remarkably this fact confirms the conclusion drawn from other premises by Mr. Godwin-Austen *, of the existence of an extended land-area during the Jurassic period, in the north-European area—reserving the discussion of the other interesting questions suggested by it for the third part of this memoir.

II. *The Cretaceous Strata of Scotland.*

There are not wanting grounds for inferring, *à priori*, that rocks of the Cretaceous system once extended over large portions of Scotland; and this inference has received the strongest support from the discovery, by numerous observers, of chalk-flints in great abundance, with transported masses of Greensand, in the drifts of the north-east of the country, as well as from the fact, recorded by the Duke of Argyll † and Professor Geikie ‡, of the existence of beds of chalk-flints, sometimes of great thickness, under the basalts of the Western Isles. But hitherto no rocks of Cretaceous age have been detected *in situ* in the British Islands to the north of Yorkshire and Antrim. During my study of the Jurassic rocks of Scotland, however, I have had the good fortune to discover very interesting Cretaceous deposits of considerable extent, though often much obscured by overlying volcanic rocks. These occur in the west of Scotland, on the mainland, and also in several of the islands, and, as might be anticipated, present characters similar to those of the equivalent strata of the north of Ireland, of which they are evidently the northern prolongation; at some points, however, they exhibit other features of much novelty and interest, for which we must seek a parallel in the Tourtia and other continental deposits. These Cretaceous strata are also of the greatest interest and importance as affording the most complete confirmation of the conclusions of the Duke of Argyll and Professor Geikie as to the Tertiary age of the Hebridean volcanic rocks.

III. *The Triassic Strata of Scotland.*

Another formation, the existence of which in Scotland has been considered by some geologists almost as problematical as that of the Cretaceous, is the Trias. The keen discussions, however, concerning the age of the now celebrated reptiliferous sandstone of Elgin appeared to many geologists to be terminated by the palæontological researches of Professor Huxley, referring to which Sir Roderick Murchison, in the last edition of 'Siluria,' wrote as follows:—"To such fossil evidence as this the field-geologist must bow; and instead, therefore, of any longer connecting these reptiliferous sandstones of Elgin and Ross with the Old Red Sandstone beneath them, I willingly adopt the view established by such fossil evidence, and consider that these overlying sandstones and limestones are of Upper

* Quart. Journ. Geol. Soc. vol. xii. (1856), pl. 1.
† Quart. Journ. Geol. Soc. vol. vii. (1851), p. 94.
‡ Proc. Roy. Soc. Edin. vol. vi. (1867), p. 72 &c.

Triassic age, and must once have formed the natural base of those Liassic and Oolitic deposits of the north-east of Scotland which I described forty years ago" *.

Most strikingly has the anticipation contained in the above passage been verified by my researches among the newer strata of Sutherland during the past year. I have been able to detect there the formation so long the subject of controversy, and to show that its relations to overlying rocks are exhibited in a section free from those sources of difficulty and doubt which have so long baffled geologists in Elginshire. In Sutherland the rocks in question are seen to be covered conformably by a great series of strata which, as will be seen from their large and distinctive faunas, represent various members of the Middle and Lower Lias. Thus, as in so many similar instances, the apparent discrepancy between the palæontological and stratigraphical evidence is dissipated by further inquiry, and the proof of the Triassic age of the beds in question is rendered complete.

The object of the present memoir is to give the results of a careful study of the small but highly interesting patches of Secondary rocks which occur in Scotland, with a view to show how far the history of the Mesozoic periods within that area can be reconstructed from them. It is proposed to divide the subject into three parts, which will be successively communicated to this Society, the first being embodied in the present paper. The three divisions of the memoir are as follows:—

I. The Secondary Strata of the Eastern Coast of Scotland.

II. The Secondary Strata of the Western Coast and Islands of Scotland.

III. A general Comparison of the Scottish Mesozoic Strata with their equivalents in England and on the Continent, and an examination of the Theoretical Questions suggested by a study of their physical characters and relations, and of the peculiarities of their faunas.

Part I.—Strata of the Eastern Coast.

I. *History of Previous Opinion.*

The coal-beds of Brora were certainly known as early as the year 1529, as is proved by an ancient Sutherland charter, which was brought under my notice by the Rev. J. M. Joass. This charter is quoted in the 'Origines Parochiales Scotiæ' (vol. ii. pt. ii. p. 727).

The earliest account of the working of the coal is contained in Sir Robert Gordon's quaint old work 'Genealogy of the Earls of Sutherland,' written in 1630.

John Williams, the author of the 'Natural History of the Mineral Kingdom,' was lessee of the Inverbrora Colliery from 1764 to 1769. He does not, however, in his work, which was published in 1810, record any of his observations and experiences in Sutherland, though he notices the peculiar characters and gives some details

* Siluria, 4th edition (1867), p. 267.

concerning the position of the remarkable rock of Stotfield in Elginshire, which contains galena (*op. cit.* vol. i. pp. 303, 401).

In 1811 Sir Humphry Davy made an examination of the rocks of Sutherland, especially noticing the strata which are found on the south-eastern coast of the county, and wrote a short account of them. These observations were never published; but the MS. and the series of specimens collected by the author to illustrate his descriptions are preserved in the Duke of Sutherland's Museum at Dunrobin.

Captain John Henderson's 'General View of the Agriculture of the County of Sutherland,' published in 1812, preserves a copy of one of the sections made during the trials for coal at the Water of Brora (Faseally).

In 1812 John Farey, sen., the well-known author of the 'Mineral Report on Derbyshire,' and the friend and correspondent of William Smith, made a professional examination of the Sutherland coal-field. His Report, which is in MS., and is dated 29th April, 1813, is a most valuable essay; it is accompanied by an admirable series of sections and maps; and in the execution of the whole of these the author has vindicated his claim to be regarded as one of the foremost among the pioneers of geological science. Farey, like Townsend and Richardson, clearly foresaw the important fruit which the discoveries of Smith were destined to produce, and, like them, sought everywhere to apply those principles which his friend taught, and to collect new facts to aid him in his generalizations. Fully recognizing the importance of the study of fossils as characterizing particular rocks, he made collections from several of the Secondary beds in Sutherland, and transmitted them to Mr. Sowerby; some of these fossils were afterwards figured in the 'Mineral Conchology.' Farey was the first to detect the fact that the coal-bearing strata of Sutherland do not belong to the true Carboniferous system, but are of Secondary age: he also traced clearly the position of the several coal-seams, and the character and effects of some of the principal dislocations to which they have been subjected. To the geologist at the present time Farey's Report is of especial service, preserving, as it does, accurate records of old pits and sections now no longer open; and I am happy to acknowledge the great services which I have myself received from it.

In 1819 Mr. Robert Bald laid before the Wernerian Natural-History Society of Edinburgh an account of the Clackmannanshire coal-field, in which he furnishes some details of the peculiarities of the strata seen at Brora. His paper was published in 1821, in the memoirs of the above-named Society (vol. iii. p. 138).

About this time Mr. George Anderson, of Inverness, an indefatigable local observer, laid before the Philosophical Society of that town a paper on the Sutherland coal-field, which appears never to have been published; his experience, however, would seem to have been subsequently placed at the service of Sir Roderick Murchison, who warmly acknowledges the assistance received from him.

In 1824 Dr. Buckland and Mr. (now Sir Charles) Lyell visited Sutherland, and recognized the fact that the coal-bearing beds were

of Oolitie, and not of Carboniferous age. No account of their researches, however, appears to have been printed.

In 1826 Mr. (afterwards Sir Roderick) Murchison visited the county, and made that careful survey of the Jurassic strata in Sutherland, Ross, and Cromarty, to which reference has already been made (Trans. Geol. Soc. 2nd ser. vol. ii. pt. 2, p. 293).

In the following year (1827) Murchison returned to the Highlands in company with Professor Sedgwick. On this occasion, the Secondary rocks were reexamined, and the first detailed study made of the Triassic rocks of Elginshire (Trans. Geol. Soc. 2nd ser. vol. ii. pt. 3, p. 353, and vol. iii. pt. 1, p. 125).

At this period Dr. Knight, of Aberdeen, had already detected the fact of the existence of chalk-flints over a large area in the county of Aberdeen; and in a paper published in the Edinburgh Philosophical Magazine in 1831, Mr. Christie called attention to the occurrence of chalk-flints at Boyndie Bay, Banffshire.

In 1832 appeared the first edition of the admirable 'Guide to the Highlands' by George and Peter Anderson, of Inverness, in which some valuable geological observations are recorded.

The same year Dr. Gordon, in a letter to Sir Roderick Murchison, read before the Geological Society, gave the first notice of the existence of a patch of Secondary rock in Morayshire at Linksfield, or Cutley Hill, near Elgin (Proc. Geol. Soc. vol. i. p. 394).

In the year 1835 the Highland and Agricultural Society published a prize essay on the 'Geology of Morayshire,' the work of Mr. John Martin. This work contains many valuable details connected with our subject. In 1838 Dr. Malcolmson showed that the beds at Linksfield presented remarkable resemblances in mineral characters to the English Wealden and Purbeck, to which period he suggested that they belonged. In the same year appeared his admirable essay on the Old Red Sandstone of Morayshire, in which he treated of the beds now placed both on palæontological and stratigraphical grounds in the Trias.

Mr. R. Hay Cunningham's 'Geognosy of Sutherlandshire,' another of the prize essays of the Highland and Agricultural Society, appeared in 1839. In this work, however, which contains such an admirable account of the Palæozoic rocks of the county, scarcely any fresh facts are added with regard to the Secondary rocks.

In 1842 appeared Mr. Duff's 'Sketch of the Geology of Moray,' in which many valuable details are given concerning the rocks of that county (which are now placed in the Trias), and also with regard to the fragments of Jurassic rocks scattered over the county, which are now proved to be transported masses included in the Boulder-clay.

Mr. Alexander Robertson, of Inverugie, laid before this Society, in the years 1843 and 1846, admirable essays on the section below the coal of Brora, showing that there were interealated in the series bands of freshwater shells, and insisting that, from the resemblance of these strata to the Wealden, they ought to be classed with that formation (Proc. Geol. Soc. vol. iv. p. 173, and Quart. Journ. Geol.

Soc. vol. iii. p. 113). The same author, in the 3rd edition of Anderson's 'Guide to the Highlands,' gave an admirable sketch of the geology of the county of Elgin. It was through the agency of the same indefatigable geologist that the fishes of Linksfield, and the first discovered specimen of *Stagonolepis*, were submitted to Prof. Agassiz, by whom they were described in the 'Poissons Fossiles.'

The year 1852 forms an important era in the history of discovery in connexion with the Secondary rocks of the east of Scotland; for then was first brought under the notice of geologists the existence of the interesting reptile *Telerpeton Elginense*, which was described by Dr. Mantell, while its position in the rocks of Elginshire was clearly pointed out by Captain Brickenden. The latter gentleman had in the previous year contributed some interesting notes to this Society on the position of the mass of Secondary rock at Linksfield (see Quart. Journ. Geol. Soc. vol. vii. p. 289, and vol. viii. pp. 97 and 100).

Hugh Miller, in his early work 'The Old Red Sandstone,' published in 1841, makes reference to the supposed Liassic strata of Eathie; and during the numerous examinations which he made of his native county and adjoining districts, he collected many very interesting observations on the Secondary rocks, which are recorded in several of his deservedly popular works, especially in 'The Fossiliferous Deposits of Scotland' (1854), 'Rambles of a Geologist' (1858), 'The Cruise of the Betsy,' (1858) and the 'Sketch-Book of Popular Geology' (1859). Many of these observations will be referred to in the following pages. Hugh Miller's most important contribution to the Secondary Geology of Scotland, however, is the account which he gives, in the eleventh and twelfth chapters of the 'Testimony of the Rocks,' of the beautiful flora, now shown to be of Upper Oolite age, of Sutherland and Ross.

The doubt which had been awakened by the discovery of *Telerpeton* as to the Old-Red-Sandstone age of the sandstones of the north of Elginshire was greatly intensified by Professor Huxley's announcement that the *Stagonolepis* of Agassiz was not a fish, as had hitherto been supposed, but a reptile of high organization, and with Crocodilian affinities. When, by the indefatigable labours of Dr. Gordon, a third species of reptile, the *Hyperodapedon Gordoni*, was brought to light, and its close affinities with well-known Triassic genera demonstrated by Professor Huxley, even the stoutest advocates of the Old-Red-Sandstone theory, including Sir Roderick Murchison, began to waver.

When the British Association met at Aberdeen in 1859, this great open question of geology was warmly discussed, many geologists taking the opportunity of examining the district; the Triassic age of the Reptiliferous sandstone was strongly maintained by Sir Charles Lyell, Mr. C. Moore, and the Rev. W. Symonds.

In the same year Dr. Gordon published his admirable *résumé* of the known facts 'On the Geology of the Lower or Northern part of the Province of Moray,' while Sir Roderick Murchison gave a discussion of the whole question in a paper read before this Society. The history of the changes of opinion on the subject can also be traced

in the several editions of Sir Charles Lyell's 'Manual of Geology,' and of Sir Roderick Murchison's 'Siluria.'

In 1863 the Old Red Sandstone theory appeared to receive some support from the discovery of footprints in the sandstones of the Tarbet Ness promontory by the Rev. Geo. Campbell and the Rev. J. M. Joass; and in the following year Professor Harkness, while admitting that the sections of Sir Roderick Murchison across Elginshire could not be maintained, and that the country was certainly traversed by great faults, yet argued that, nevertheless, the stratigraphical evidence was in favour of our regarding the Reptiliferous sandstone as belonging to the Old Red.

Professor Huxley's new and detailed account of *Telerpeton* in 1867 was followed in 1869 by the description of *Hyperodapedon Gordoni*; and in this latter memoir it was shown that the *same genus* occurs in the Trias of Warwickshire, Devonshire, and India. This discovery was admitted by Sir Roderick Murchison and most other geologists to be conclusive as to the Triassic age of the beds.

While the attention of geologists was concentrated on the Reptiliferous sandstones, but little fresh light was thrown on the other Secondary deposits of the east coast of Scotland. Mr. C. Moore, in 1859, published his reasons for considering the strata at Linksfield of Rhætic age; which view was supported by Professor Rupert Jones on a study of some of the fossils. The Rev. W. Symonds stated in 1860 that a collection of Eathie and Shandwick fossils, on being submitted to some able Cotteswold palæontologists, were pronounced by them to be of Upper Oolite and not of Liassic age. Hugh Miller had already suggested that part of these strata were probably Oolitic, while Professor Phillips in 1870 stated that his examination of Lieut. Patterson's collection led him to infer that they belonged to the Oxfordian*. Dr. Gordon, in 1863, published some notes on the physical relations of the secondary strata in Ross and Sutherland; and in his most valuable work the 'Scenery of Scotland,' Prof. Geikie in 1865 added some important observations on the same subject.

In making a general reexamination of the Secondary deposits in the east of Scotland, some facilities have fortunately been afforded to me which were not within the reach of previous observers. Thus the new railway which passes along the east coast of Sutherland has yielded several new and interesting sections in the various cuttings; while the coal-strata, which had remained undisturbed for 44 years, were during the time of my visit again opened up to observation at several points.

By the establishment at Dunrobin of a Museum illustrative of the

* Professor Phillips has recently furnished me with an extract from his notebook, which shows that the inspection of Lieut. Patterson's collection in 1866 convinced him that the beds at Eathie and Shandwick belonged to two different horizons, and that the peculiar long Belemnites were found only at the former place. Unfortunately, some specimens with a wrong locality affixed to them, afterwards came into the Professor's possession, and led to the less precise statements in his account of these Belemnites in the memoir.

natural history, geology, and archæology of the county from which he derives his title, and of which he is almost the sole proprietor, His Grace the Duke of Sutherland has conferred a great benefit on science; and the same nobleman has placed myself under deep personal obligations by allowing me the freest access to the various documents and plans which could in any way aid me in carrying on my studies. The kind solicitude in my behalf of His Grace's Factor, Joseph Peacock, of Rhives, demands my warmest acknowledgments. To very many local collectors and observers I am indebted for the opportunity of studying their specimens, and for the communication of valuable facts. Among these I especially desire to render my warmest thanks to Mr. Grant, of Lossiemouth, the Rev. J. Morrison, of Urquhart, Mr. Martin, of Elgin, Mr. Edward, of Banff, Professor Nicol, of Aberdeen, Mr. Hugh Miller, junior, Miss C. Allardyce, of Cromarty, Mr. Fowler, of Golspie, and Mr. M'Corquodale, of Dunrobin.

But to two local geologists, whose names are well known to this Society, I am laid under still deeper obligations. To the Rev. J. M. Joass, of Golspie, and the Rev. Dr. Gordon, of Birnie, near Elgin, I am indebted for that constant assistance and ever-ready advice which they are so well qualified to give with regard to their respective districts, and which is so indispensable to and difficult of attainment by an investigator in a district which is new to him. The kind interest which they have taken in my labours, and their constant solicitude in seeking to bring useful materials to aid me in the difficult task which I had undertaken, lay me under a debt of gratitude which, though I can never discharge, I yet gladly take the present opportunity of acknowledging.

The orthography of all local names in the present memoir has been kindly determined for me by my friend Mr. Joass; but in doing this he has, at my suggestion, consulted the convenience of geologists visiting the country, rather than the strict requirements of Gaelic scholarship.

In studying the series of fossils from the east of Scotland, many of which are new to science, I have to acknowledge the valuable assistance afforded to me by Mr. Carruthers, Dr. Lycett, Prof. P. M. Duncan, Sir Philip Egerton, Prof. T. Rupert Jones, and Mr. Davidson. The last-mentioned palæontologist has kindly added a note to this paper on some species of Brachiopoda of especial interest; many other new forms will find a place in monographs, now in course of preparation, on the groups to which they belong; the remainder will be described, in connexion with new species from the West Coast of Scotland, in a supplement to this memoir. In these palæontological studies, the assistance of Mr. Etheridge's great experience, always most liberally rendered to me, has been invaluable.

II. *Physical Relations of the Secondary Rocks on the East Coast of Scotland.*

The Secondary rocks which are known to occur *in situ* on the

east coast of Scotland, consist almost exclusively of more or less isolated patches, often of small extent, on the shores of the Moray Firth. It is possible that the Boulder-clays and other drifts, which attain to so great a thickness in the north-east of Scotland, may conceal other similar patches; these we can only expect to be revealed to our observation through some favourable combination of circumstances, in deep natural or artificial sections.

The masses of Mesozoic strata which are seen at various points round the Moray Firth, are found lying indiscriminately against the different Palæozoic rocks—namely, the several members of the Old Red Sandstone, the metamorphic rocks of the Lower Silurian, and the great bosses of granite. The Secondary strata are usually greatly bent and faulted, and often, especially near their junction with the Palæozoic rocks, very violently contorted. The strata are shown by their palæontological characters to be of various ages, from the Trias to the Upper Oolite, and, as will appear from the present memoir, enable us to reconstruct nearly the whole of the Jurassic series as developed in this northern district.

None of the beds exhibit evidence of having been beaches lying upon the old Palæozoic rocks with which they are now in contact, and made up of their fragments. Common as this phenomenon is, as we shall see hereafter, on the west coast of Scotland, we find nothing resembling it on the east coast, where the conglomerates and grits are never made up of the detritus of the primary rocks lying nearest to them; but on the contrary the various beds of the series exhibit indications of the most various modes of origin—deep-sea marine, shallow-water marine, littoral, brackish-water, freshwater, and terrestrial.

It is evident on an examination of these patches of Secondary strata that they form the last remaining vestiges of extensive formations which once covered considerable areas, but have been almost wholly removed by the enormous denudation to which the district in which they are developed has been subjected; it is equally plain that the present position of the patches among the older rocks must be ascribed to accidental causes, which have operated since their original deposition. In almost every instance we can trace the *proximate* causes of the preservation of the patches, either in the presence of rocks of especial hardness and capability of resisting denuding influences, like the cherty rock of Stotfield, the indurated sandstones of Braamberry Hill, the hard grits of Kintradwell and the breccias of Helmsdale—or in the position and protective influence of surrounding masses of Palæozoic rocks, as at Eathie and Shandwick. The more *remote* causes which have contributed to the preservation of the several patches I shall presently demonstrate. That, even as late as the glacial period, the Secondary rocks covered much more extensive areas than at present appears to be proved by the great abundance of their fragments in the Boulder-clay of the east of Scotland.

The areas covered by the Secondary rocks which have been as yet discovered are, as already intimated, very small; and as they are

almost always deeply covered with masses of Boulder-clay, gravels, glacier-moraines, raised beaches, and sand dunes, they are seldom exposed to our observation, except in reefs on the shore or in the deep ravines cut by mountain-torrents.

The patches of Secondary strata at present known on the east coast of Scotland are as follows, the enumeration proceeding from north to south (see Map, Plate VII.):—

Caithness.—I. A small patch forming reefs on the shore a little north of Green Table Point. *Age.* Upper Oolite.

Sutherland.—II. Several masses of strata almost continuous, between Green Table Point and Helmsdale. *Age.* Upper Oolite.

III. A continuous band of strata between Helmsdale and Allt Chollie (Colyburn). From $\frac{1}{4}$–$\frac{1}{2}$ mile wide. *Age.* Upper Oolite.

IV. A tract extending from Kintradwell to near Golspie. This attains a breadth of more than 2 miles at Brora, and is by far the most important development of the Secondary rocks in the east of Scotland. *Age.* From the Trias to the Upper Oolite (inclusive).

Ross.—V. A patch of clays seen at low water on the shore at Port-an-Righ, near the mouth of the Guillam Burn, and a little south of Shandwick Bay. It extends for about three-quarters of a mile between two projecting spurs of Old Red Sandstone. *Age.* Upper part of Middle Oolite.

VI. A similar but smaller patch, only half-a-mile south of the last, at a place called Cadh'-an-Righ. *Age.* Base of Middle Oolite, and top of Lower Oolite.

Cromartyshire.—VII. Beds similarly exposed on the shore at Eathie Bay over a length of about three quarters of a mile. *Age.* Upper Oolite.

Elginshire.—VIII. The ridge of low sandstone hills between Burghead and Stotfield Head, and part of the ridge three miles to the southward, and on the south side of Loch Spynie. The boundaries of these patches are altogether obscured by drift. *Age.* Trias and Lower Oolite.

Besides these points, at which the strata in question are undoubtedly *in situ*, there are a number of places scattered through the counties of the north-east of Scotland, especially Elginshire, Banffshire, and Aberdeenshire, where very numerous fragments of the Secondary rocks have been detected enclosed in the Boulder-clays, which are there so extensively developed; and from these boulders very considerable and interesting series of Secondary fossils have been obtained. In some cases the transported masses are of enormous size, resembling the similar blocks found in the Midland districts of England, and referred to by Prof. Morris* and Prof. Ramsay†, and which will be described in detail in a forthcoming

* Quart. Journ. Geol. Soc. vol. ix. (1853) p. 317.

† *Ibid.* vol. xxvii. (1871) p. 252.

memoir of the Geological Survey. In other instances, although the individual blocks are not large, there are evidently local accumulations of fragments from the same bed, perhaps the deposits of single icebergs. The most notable example of the former kind is that of Linksfield, which has been several times brought under the notice of this Society; while striking instances of the latter kind occur at Inverugie, Lhanbryd, and Urquhart; these and similar cases have led to reports of the existence of Secondary strata *in situ*, afterwards proved to be erroneous*.

With regard to the general relations of the patches of Secondary strata in the east of Scotland to the great masses of Palæozoic age which constitute the Highlands, the conclusions to which Sir Roderick Murchison appears to have been led by his first examination of the strata on the east coast of Sutherland were as follows:—That the Jurassic beds were deposited in a basin formed of the Old Red Sandstone rocks, and that subsequently a great upheaval of granite *in a solid condition* caused the vast amount of disturbance and contortion seen in some parts of the strata of the former series†. Later observations appear to have convinced Sir Roderick Murchison that some portions of what he originally regarded as a granitic rock, were really stratified and metamorphic‡; but he has not in his later writings sought to harmonize this fact with the theory of the relations of the rocks which he originally put forward. In the section across Sutherland, published in the 'First Sketch of a Geological Map of Scotland' in 1861§, the Old Red Sandstone and the Jurassic series are represented, probably through inadvertence, as following the Silurian in nearly conformable sequence.

Mr. Hay Cunningham, in his examination of the county of Sutherland in 1839, clearly perceived that all the southern part of the crystalline rocks, against which the Jurassic strata of that country lie, are really stratified and metamorphic, and not granitic. In his map he indicates, with tolerable correctness, the range of these metamorphic rocks, though he does not carry them sufficiently far to the southward‖; and he further identifies them with the great series of gneissic rocks which covers so large a part of Sutherland. Rejecting, on these grounds, Murchison's explanation of the peculiar phenomena of the district by the upheaval of granite in a solid condition, Mr. Cunningham himself put forward a theory to account for them, which, however, is likely to find but little acceptance among geologists at the present day. He argues that the Jurassic strata might have been originally deposited in their present condition of high inclination, and that the "brecciated" appearance

* See Duff, 'Geology of Moray,' 1842; Prestwich, Quart. Journ. Geol. Soc. vol. ii. p. 545; Hugh Miller, 'Rambles of a Geologist,' &c. 1858; &c. &c.

† Trans. Geol. Soc. 2nd ser. vol. ii. pt. 2. pp. 295, 307, 354, &c., pl. 31.

‡ *Ibid.* pt. 3. p. 355.

§ This Map is republished in Geikie's 'Scenery of Scotland,' 1865.

‖ See also the Map published by the Rev. J. M. Joass, to illustrate the distribution of the auriferous deposits in Sutherland, Quart. Journ. Geol. Soc. vol. xxv. (1869), pl. xiii.

of some of them (that extraordinary phenomenon which has justly excited the wonder and severely taxed the ingenuity of Murchison and other geologists who have examined and attempted to account for it) might be due to the breaking-up and redeposition of some of the beds*.

I shall now proceed to describe the facts which I have been able to observe concerning the position of the Jurassic strata, and their relations to the Palæozoic rocks, and then indicate the conclusions to which they point as to the circumstances of deposition and of the subsequent disturbances of these strata. By this means I hope to be able to demonstrate what were the *remote* causes which led to the preservation of the interesting masses of Mesozoic strata to be described in the present memoir.

It will be convenient, in order to make the subject as clear as possible, to describe a line of section passing across the centre of the most important Jurassic area, where the rocks attain their greatest development and present the most satisfactory exposures. Such a line of section we have, as pointed out by Sir Roderick Murchison, passing through Clyne and Brora, and crossing a breadth of upwards of two miles of Secondary strata. When the main facts with regard to this most important section have been established, it will only be necessary to refer, in more general terms, to the various sections to the north and south of it respectively which serve to illustrate the relations of the Secondary to the Primary strata.

§ 1. *Description of the Section through Beinn-Smeorail, Clyne Kirk, and Brora*, N.W. to S.E. (fig. 1).

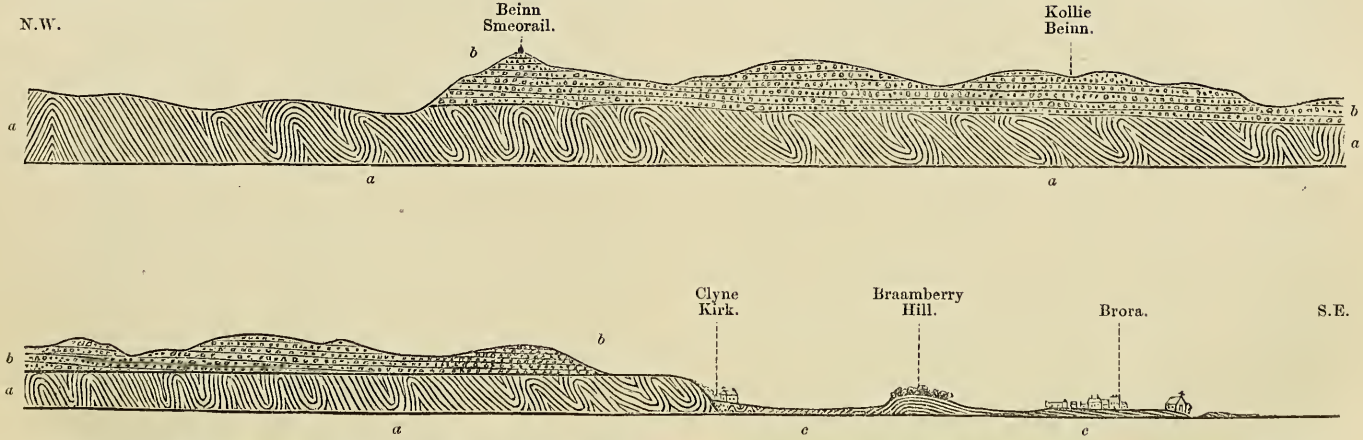
The great series of metamorphic rocks which covers all the central parts of Sutherland, have now, through the discovery of fossils by Mr. C. Peach, and the study of the physical relations of the beds by Sir Roderick Murchison and Professors Ramsay, Geikie, and Harkness, been referred to the age of the Lower Silurian†. These rocks, which have been very happily termed by Murchison "altered flagstones," present the most varied characters, passing from flaggy quartzites or altered sandstones, in which crystalline minerals just begin to appear along the planes of stratification, up to the most highly granitic gneiss, and perhaps into true granites. The prevailing dip of these strata is towards the south-east; and they are usually inclined at very high angles, often greatly contorted, and sometimes traversed by numerous veins of granite, quartz, felspar, &c. As a rule they do not form striking elevations, and give rise to but tame and monotonous scenery‡.

* "On the Geognosy of Sutherlandshire," by R. J. H. Cunningham (1839), p. 37, published in vol. xiii. of the 'Transactions of the Highland and Agricultural Society of Scotland.'

† Quart. Journ. Geol. Soc. vol. xiv. (1858) p. 501; vol. xv. (1859), p. 353; vol. xvi. (1860), p. 215; vol. xvii. (1861), p. 171; vol. xvii. (1861), p. 256; vol. xviii. (1862), p. 331.

‡ These strata have been more particularly described by the Rev. J. M. Joass, Quart. Journ. Geol. Soc. vol. xxv. (1869), p. 314.

Fig. 1.—*Typical Section, illustrating the relations of the Secondary Deposits to the Palæozoic Rocks of Sutherland.*



a. Lower Silurian gneissose rocks, greatly contorted. *b*. Lower Old Red Sandstones and Conglomerates made up of fragments of *a*, and resting on the denuded edges of its strata. *c*. Middle and Upper Oolites, exhibiting evidence of great disturbance at their junction with *a*.

Lying upon the upturned and denuded edges of these Silurian rocks there is, on the south-east coast of Sutherland, a series of outlying masses, forming a belt about five miles wide, and consisting of the Lower division of the Old Red Sandstone system. This is constituted by nearly horizontal beds of the well-known and highly remarkable rock of the Old Red Conglomerate (which is made up of fragments of all sizes, waterworn and angular, of the subjacent Silurian rocks) alternating with, and frequently graduating into, more or less flaggy beds of Red Sandstone composed of what Sir Roderick Murchison aptly calls "*granitic sand*." Nothing can be more striking than the proofs of unconformity between the Silurian and Old Red Sandstone rocks: the former have evidently been not only contorted and metamorphosed, but also upheaved and denuded before the deposition of the latter; and the older strata have, moreover, furnished the materials of which the younger are composed.

The relation of these two series of rocks may be well seen on both sides of Loch Brora, where the tops of the fantastically shaped mountains, which culminate in Beinn-Smeorail and Beinn-Hourn, are formed of the Old Red Conglomerate and Sandstone, while their flanks, wherever mountain-torrents have cut through the old lateral glacier-moraines which cover them, are seen to be formed of the highly contorted Silurian rocks*. On the south-eastern side of the band of the Old Red strata the Silurian distinctly appears; but the rock, being of a somewhat peculiar character, was originally mistaken for granite. It is almost entirely made up of quartz and felspar, and is generally in a more or less altered condition, being divided by numerous joints into small angular fragments the surfaces of which are decomposed and stained with oxide of iron†. When, however, a sufficiently large surface of fracture can be obtained, the laminar arrangement of the crystalline materials of the rock is perfectly manifest. Mr. Cunningham states that a rock of precisely similar character forms part of the series of strata, now recognized as Silurian, at Beinn-Laoghal and some other points in the interior of Sutherland; and fragments of the rock certainly occur as pebbles in the Old Red Conglomerate.

In the admirable section exposed in the ravine near Clyne Kirk‡ the Silurian rocks, which rise to the height of about 500 feet (at which elevation their greatly contorted strata are seen to be capped by the nearly horizontal Old Red Sandstone beds), terminate abruptly;

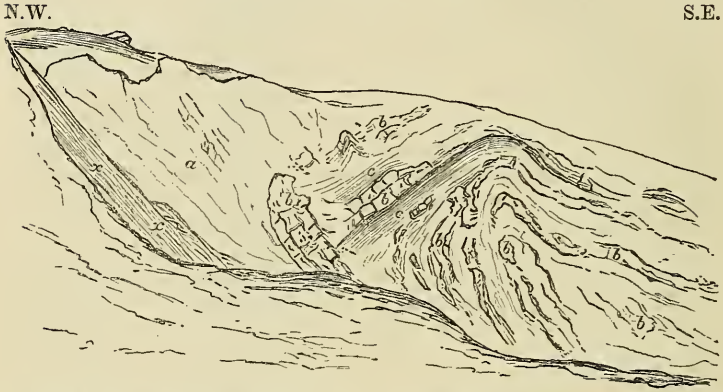
* Near Kilcallumkil (Gordon Bush) a great mass of Old Red Sandstone has tumbled from the mountain above nearly to the level of the Loch; and in it a quarry has been opened. Nowhere can the geologist find better illustrations of glacial phenomena than on the shores of the exquisitely beautiful Loch Brora. Of especial interest are the numerous terminal moraines, which mark the gradual retrocession of the glacier of Strath Brora, and one of which still dams up the present lake. Professor Geikie has referred to this most interesting locality in his admirable book on the Scenery of Scotland, p. 203–4.

† This rock affords an admirable material for macadamizing roads, as it falls when quarried into suitable angular fragments, without needing the labour of the "stone-breaker."

‡ See Cunningham, 'Geognosy of Sutherlandshire,' pl. vii.

and lying against them, but rising to a much smaller height, on account of their comparative softness, the Jurassic beds appear. The accompanying sketch (fig. 2) shows the appearance of the junction

Fig. 2.—*Section in the Ravine above Clyne Kirk, showing the junction of the Secondary and Palæozoic rocks.*



x. Metamorphic (Silurian) rocks. *a*, *b*, *c*. Jurassic Rocks.
a. Sand and sandstone so broken up that the stratification is undistinguishable.
b. Beds of coarse white and yellow sandstone.
c. Finely laminated, highly carbonaceous sand and clay, } greatly contorted.

of the Palæozoic and Mesozoic strata on the north-east side of this gorge. The Silurian rocks (*x*) form the precipice, over which the stream falls in a fine cascade. The Jurassic rocks here consist of sandstones, argillaceous sands with much carbonaceous matter, and

Fig. 3.—*Sketch of the Oolitic beds seen in Allt-Chollie (Colyburn), illustrating the manner in which they are crushed and broken near their junction with the Palæozoic rocks.*

some thin beds of clay: these strata do not yield sufficiently perfect fossils to enable us to fix their exact place in the geological series; but, judging from their mineral characters, I am inclined to refer them to the Upper Oolite. At (*a*) the strata are very obscure, being

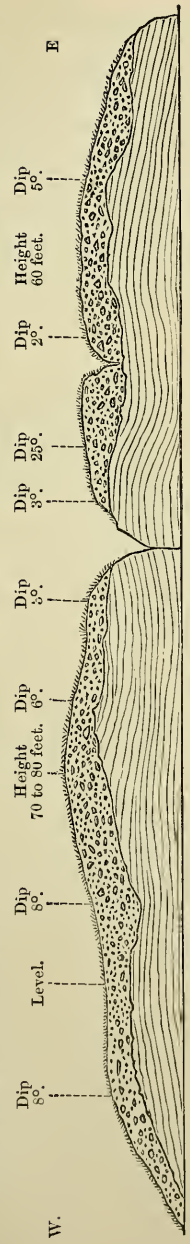


Fig. 4.—*Section of the Middle Oolite beds (Ornatus-Clays), as seen in the Bluff on the north side of the River Brora, illustrating the rolling undulations into which the Jurassic Strata are thrown at some distance from their junction with the Primary Rocks.*

covered with slipped masses and vegetation; but it is evident that the continuity of the sandstones is completely broken up, and that the rocks are in the condition so frequently observed at their contact with the Palæozoic strata, and which is well illustrated by the sketch (fig. 3) of the rocks seen in Allt-Chollie (Colyburn) four miles to the north of Clyne Kirk. At this place the harder beds of the Jurassic sandstones are seen, for a distance of about 100 yards from their junction with the Palæozoic rocks, to be broken up into fragments of various sizes, which lie in every possible position in the midst of a mass of débris formed by the crushing of the softer beds. This appearance was well described by Sir Roderick Murchison at this and several other points*. Returning to the ravine at Clyne Kirk, we find that at some little distance from the junction with the Silurian the beds of sandstone (*b*) and of black argillaceous sand (*c*) are capable of being traced, and are seen to be bent into sharp folds accompanied by slight dislocations. The disturbance of the Jurassic beds diminishes as we remove further from their junction with the Palæozoic rocks.

Between Clyne Kirk and Braamberry Hill the Secondary strata are concealed; but they probably lie in a series of long curves, in some cases broken across by faults, as illustrated by the section (fig. 4, which is drawn to scale) exposed in a bluff on the north side of the river Brora, where the rocks consist of marine sandy clays of Middle Oxfordian age. At Braamberry Hill the sandstone strata, which overlie the clays just mentioned, form an anticlinal, the rocks of which, owing to their superior hardness, resisted denudation; and thence to Brora, as seen in the gorge of the river, the strata

* Trans. Geol. Soc. 2nd ser. vol. ii. pt. 2. pp. 304 and 307; *ibid.* pt. 3. p. 354, &c.

lie with a dip gradually diminishing in amount till it does not exceed 4°*.

The section just described in detail may be regarded as typical; and the relations exhibited by the Jurassic strata here are found to characterize them wherever they appear in the north-east of Scotland. They almost everywhere offer evidence of considerable disturbance and faulting. At the points furthest removed from their contact with the Palæozoic rocks, this disturbance is at its minimum; but as we approach these latter, the angle of dip is found to increase, the folds become shorter and sharper, and the dislocations more numerous, while at the actual junction of the two series of strata the younger ones are often crumpled and crushed in the most remarkable manner.

§ 2. *Relations of the Strata North of the typical line of Section.*

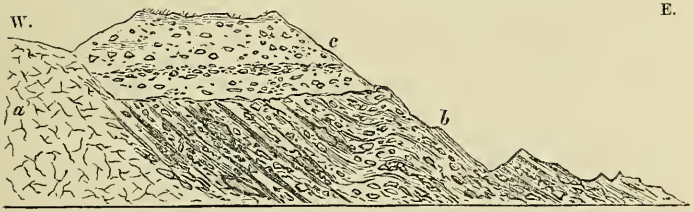
Silurian strata with characters similar to those already described, and containing veins of white quartz, red granite, &c., are found rising to a height of from 500 to 600 feet between the burns of Clyne Kirk and Kintradwell, in the latter of which they are again seen traversed by veins of quartz and felspar, the latter sometimes decomposed into kaolin. I am indebted to Captain Houston, of Kintradwell, for guiding me to these sections. At the openings of the ravines of Achrimsdale, Clyne-Milltown, and the small nameless burn just north of Kintradwell there are exposures of the Jurassic strata; but the contact of these with the Silurian strata is not seen. The interesting section of Allt-Chollie (Colyburn) has been already described; and in Allt-na-cuil and some smaller ravines to the north, though the actual junction is not exposed, the Jurassic strata are evidently greatly disturbed near their contact with the Silurian.

Near the Lothbeg river and from that point northwards the Silurian gneiss passes into or is replaced by the beautiful red, often porphyritic granite, which covers a considerable area on the confines of Sutherland and Caithness, and forms the great mass of the Ord. Along this portion of the coast the Jurassic strata are in contact with the granite or with the thin strip of Middle Old Red Sandstone (Caithness flags) which flanks it for a distance of five miles, and which will be more particularly noticed hereafter. Between Lothbeg and Helmsdale the strip of Oolitic rock, which is from a quarter of a mile to half a mile wide, is cut through by a number of brooks; and in some of these, especially in Allt Cuil-nan-Gabhar (Culgour Burn), Wester Gartie Burn, Midgartie Burn, and Allt-gharashtiemore (Gartymore Burn), the rocks, as they approach the line of their junction with the Old Red strata, are seen to be more and more disturbed. About Helmsdale the coast is formed by the granite, the Jurassic strata having been wholly denuded away; and north of that town the latter form only a very narrow strip, which is cut through in many places by small inlets of the sea and deep ravines. Some-

* See also Murchison in Trans. Geol. Soc. 2nd ser. vol. ii. part 3. p. 55.

times the cliff is formed of granite, and the Jurassic beds are only seen in a violently contorted state in the reefs on the shore; at other points a mass of Oolitic strata highly inclined appears as if attached to the face of a precipice of granite; while again low promontories projecting from the mountains of granite which come down to the shore are seen to be composed of the same greatly disturbed beds. The most noteworthy example of this kind is afforded by the Dunglass, or Green Table, a peninsular mass, composed of highly inclined Oolitic rocks capped by Boulder-clay, which, projecting from the granite* mountain of the Ord, forms the boundary between the counties of Sutherland and Caithness. This singular spot, of which I have given a section (fig. 5), formed the appropriate lo-

Fig. 5.—*Section at Dunglass (Green Table Point).*



a. Granite of the Ord.
b. Upper Oolite—"Brecciated beds."
c. Boulder-clay.

cality of an ancient settlement in the Stone age, as I am informed by my friend Mr. Joass. North of the Green Table the Jurassic strata are found in the county of Caithness, in a patch of highly inclined rock exposed only at low water.

The remarkable features exhibited by the reefs of these rocks exposed on the shore, where by their sudden variations in dip and strike they clearly manifest their crushed and crumpled condition, have been well described by Sir Roderick Murchison, and are illustrated by the changes of dip which he has recorded on his map†. The striking appearances which these reefs present are greatly heightened by their being composed of those wonderful "brecciated beds" to which more particular attention will be directed in the sequel.

§ 3. *Relations of the Strata South of the typical line of Section.*

The peculiar Silurian rock of Clyne Kirk is seen again in a ravine

* That the great mass of this granite is of very ancient date, and that it has even furnished materials to the Old Red Conglomerate, there appears to be no reason to doubt. Sir Roderick Murchison has pointed out that it could not have been in a molten condition since the Jurassic period; for the rocks of that age, though greatly disturbed, are never metamorphosed or penetrated by veins. Below the bridge at Lothbeg, a section, unfortunately somewhat obscure, exhibits veins of granite apparently proceeding from the mass of the Ord and traversing Old Red Sandstone strata. Can it be that we have evidence here of the formation of a granite at the same point at widely different periods?

† Trans. Geol. Soc. 2nd ser. vol. ii. part 2. plate xxxi.

to the southward, and between it and Loch Brora, and at a number of small exposures along the mountain-side. They are also seen on the sides of Loch Brora, wherever the streams have cut sufficiently deep to pass through the thick masses of moraine-matter which mask the flanks of the mountains on either side of Strathbrora.

South of the Loch we find in the Allt-Duchary * an admirable exposure of the metamorphic (Silurian) strata, which here consist in parts of a rock like that of the Clyne-Kirk gorge, but in other parts of red and gray fine-grained gneiss, penetrated by veins of red granite, and identical in character with the great mass of the Silurian strata of the district.

The next point at which a section is cut through the great mantle of glacial detritus which covers the country is in the Sputie Brook. Here the Jurassic sandstones, which are tolerably well exposed at several points about Uppat, are seen in the bed of the brook; and at a short distance above, the Old Red Sandstone and Conglomerate are found *in situ*, having been brought to a much lower level than near Loch Brora by the southerly dip of the strata, which seems to be here greatly increasing in amount; so that the Old Red nearly or quite overlaps the Silurian at this spot.

At several points above Uppat and Dunrobin the Jurassic sandstones and clays are found dipping at considerable angles, but no actual junction of the Primary and Secondary rocks is exposed. It is evident, however, that the Jurassic strata lie against the Old Red Sandstones and Conglomerates, and that near the line of contact they are greatly disturbed; in one place they are seen dipping N.E. 15°, while at a distance of about a quarter of a mile they dip S.W. 30°. These sections are observed in sandstone pits opened in the great deer-forest above Dunrobin Castle; but here the surface of the country is so greatly concealed as to render hopeless the task of tracing out in detail the curves and dislocations of the strata.

In Dunrobin Glen the Old Red Sandstone strata show considerable signs of disturbance. Triassic strata appear, as will be hereafter described, lower down the glen; but no actual contact with the Old Red is seen. At Rhives, near Golspie Inn, and in the cliff and on the shore between Dunrobin and Golspie the same Secondary rocks occur; and these are the last localities at which they have been detected in the county of Sutherland. Southward the beds of the Lower Old Red Sandstone are by their dip brought down to the sea-level; and at the extreme southern extremity of the county of Sutherland, higher and fossiliferous strata of the same system make their appearance †.

The shores of the Moray Firth, with those of the several inlets which open into it, namely Loch Fleet, Dornoch Firth, Cromarty Firth, and Inverness and Beauley Firths, are almost wholly composed of the various strata of the Old Red Sandstone, which succeed one another in a regular manner, and with usually slight dips. But

* Trans. Geol. Soc. 2nd ser. vol. ii. pt. 3. p. 355.

† Murchison, Quart. Journ. Geol. Soc. vol. xv. (1859) p. 398. Joass. *ibid.* vol. xxv. (1869) p. 318.

along a line striking N.E. and S.W., and passing through the town of Cromarty, the metamorphic strata of Silurian age are upheaved; and this movement has been attended with great disturbance of the Old Red Sandstone strata, which, in the neighbourhood of the gneissose, quartzose, and schistose rocks of the Silurian, are seen lying at high inclinations and with numerous folds. The remarkable ridge of metamorphic rocks is cut through by the present entrance to the Cromarty Firth *, and forms those striking headlands the North and South Sutors of Cromarty. The length of the ridge of Silurian rocks is about nine miles; but certain masses of granite which appear to the S.W. may probably be considered a continuation of it. A glance at the position of this ridge of hard rocks will suffice to show to what an extent the existence and form of the two great eastern peninsulas of Ross-shire, Easter Ross and the Black Isle, have been determined by it.

Lying against this ridge of upheaved and disturbed strata we find on the shore three of the patches of Jurassic strata already referred to, namely those of Port-an-Righ, Cadh'-an-Righ, and Eathie Bay. Situated in small recesses of the coast, between headlands of the harder rocks, these patches, which have already been denuded away to a level below that of high water, are evidently the last vestiges of a tract of land which once fringed the high lands of Ross, in the same manner as the low Oolitic district in the south-west of Sutherland now forms a border to the mountains of that county. No one can study these two remarkable and interesting districts without being struck by the fact that here we have a repetition of the same phenomenon, produced by the action of the same succession of causes, but exhibited to our study at two different stages of its history. The two districts mutually explain one another; and it is evident that while on the one hand the south-east coast of Ross must once have exhibited a tract of low-lying land composed of Jurassic strata like that of Brora, this last must at some future period be reduced, by the continued action of existing causes, to a condition analogous to that of the former.

About a mile southwards from the village of Shandwick there appears the first of the patches referred to †. The strata are seen only at low water, and then present a singular appearance: they are bent into long folds and dip seawards at a considerable angle; and being composed of indurated shales with a few harder bands of argillaceous limestone, they have been worn into a series of step-like ridges, which have been not unaptly compared by Sir Roderick Murchison to the seats of an ancient amphitheatre. These strata are also broken up by a number of small transverse faults, which have produced lateral displacement of the beds. The relations of these strata to those of the Old Red Sandstone against which they lie are illustrated by the plan and section, figs. 6 and 7.

* See Murchison, Trans. Geol. Soc. 2nd ser. vol. ii. pt. 3. p. 355. Geikie, 'Scenery of Scotland,' p. 132.

† First described by Sir Roderick Murchison, to whom it was pointed out by Sir George Mackenzie. Trans. Geol. Soc. 2nd ser. vol. ii. pt. 2. p. 307.

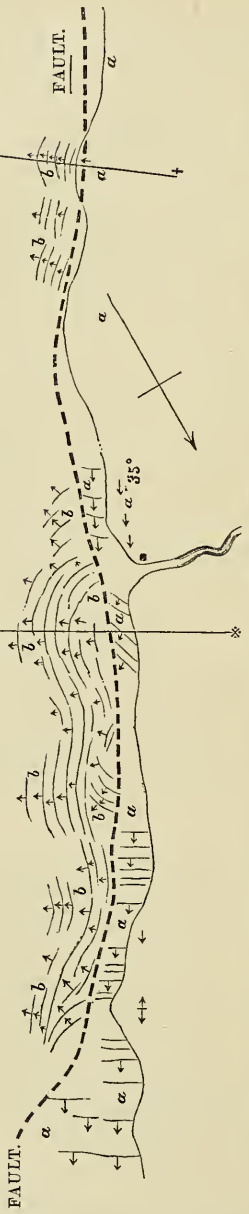


Fig. 6.—*Plan of the Reefs of Secondary Rocks exposed at low water on the shores of Easter-Ross, between Shandwick Bay and Cadh'-an-Righ.*

a. Old Red Sandstone and Conglomerate. *b.* Middle Oolite clays and limestones. ** Section, fig. 7. †† Section, fig. 8.

At less than half a mile southward, but quite separated from the last, we find the second patch of Jurassic strata, that of Cadh'-an-Righ. It is in part composed of indurated shales, similar to those of Port-an-Righ; but underneath these appear freshwater or estuarine beds of clay, sandstone, and coal. Their relations to the Old Red Sandstone against which they lie, but to which, as at Cadh'-an-Righ, they are quite unconformable both in strike and dip, are shown in the section, fig. 8.

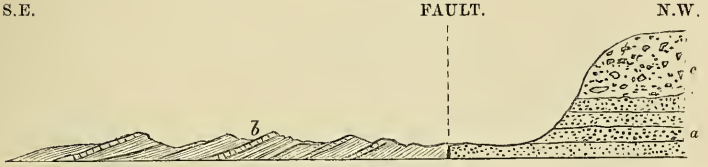
I am not aware that any patch of the Secondary strata *in situ* has been detected to the south-west over the next seven miles. The numerous fragments of these rocks thrown up on the shore, however, render it not improbable that such beds may exist in some of the submerged rocks and skerries which abound along this coast.

In Eathie Bay occurs another interesting patch of Jurassic rocks, which, first pointed out by Sir Roderick Murchison *, has been frequently illustrated in the writings of other geologists, especially those of the late Hugh Miller. As in the last two instances, the beds are only seen during low water; they are composed in one part of alternations of shales and argillaceous limestones, with some beds

* Trans. Geol. Soc. vol. ii. pt. 2. p. 307.

of white sandstone at the base, and in another part of clays and argillaceous grits, with much vegetable matter. They lie in part

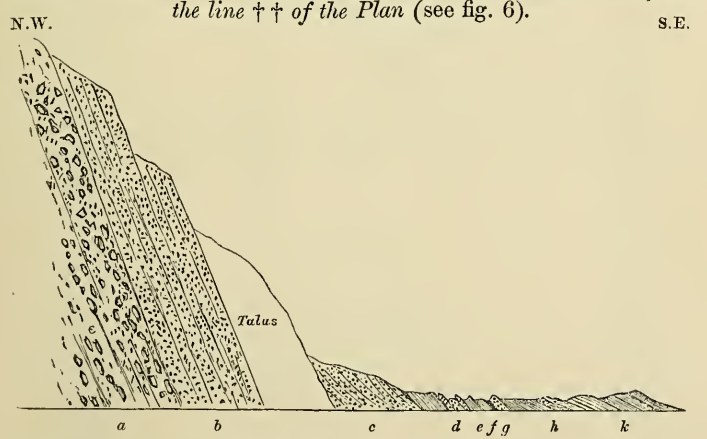
Fig. 7.—*Section across the Reefs at Port-an-Righ, along line * * of the Plan* (see fig. 6).



a. Beds of Old Red Sandstone, dipping N.E.
b. Shales and limestones of the Middle Oolite, dipping S.E.
c. Boulder-clay, capping Old Red Sandstone in the cliffs.

against the contorted Silurian rocks, and in part against the highly inclined strata of the Old Red Sandstone, though the actual contact

Fig. 8.—*Section across Shore and Reefs at Cadh'-an-Righ, along the line † † of the Plan* (see fig. 6).



Old Red Sandstone.	*a*.	Old Red Conglomerate.
	b.	Old Red flaggy sandstones. (Talus.)
Lower Oolite.	*c*.	White sandstones and light blue clays (estuarine).
	d.	Alternations of variegated clays, sandstone, and argillaceous limestone (freshwater fossils).
	e.	Shelly bands and clays (mixture of freshwater and marine shells and numerous plant-remains).
	f.	Thin coal-seam.
Middle Oolite.	*g*.	Sandstone with many marine fossils ("Roof-bed").
	h.	Sandy clays with marine fossils.
	k.	Dark blue clays with septaria (marine fossils).

is concealed by the shingle of the beach. One of the shafts (the northern one) sunk by an unfortunate speculator, who hoped to find

coal here, appears to have commenced almost on the line of junction, and, after passing through a small thickness of the Oolitic rocks,

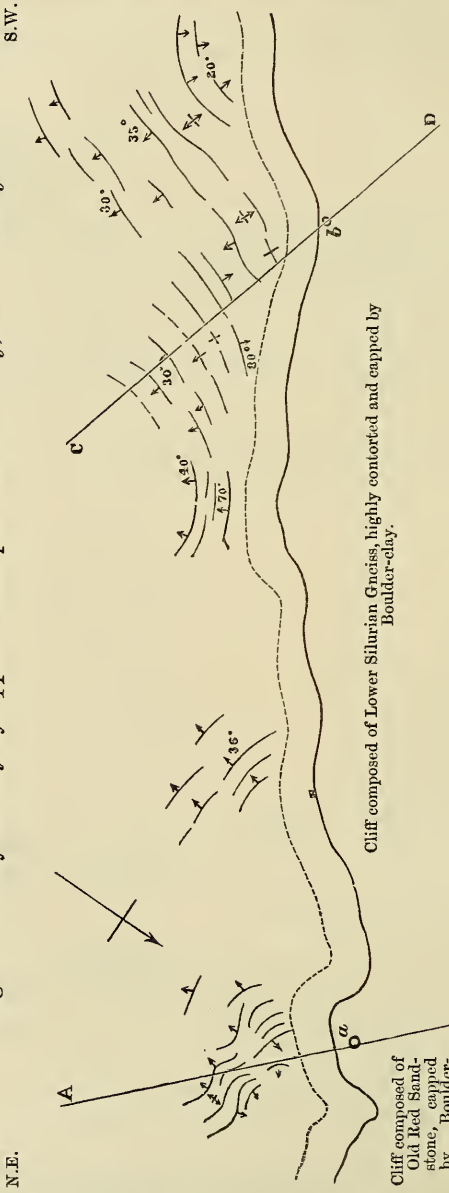
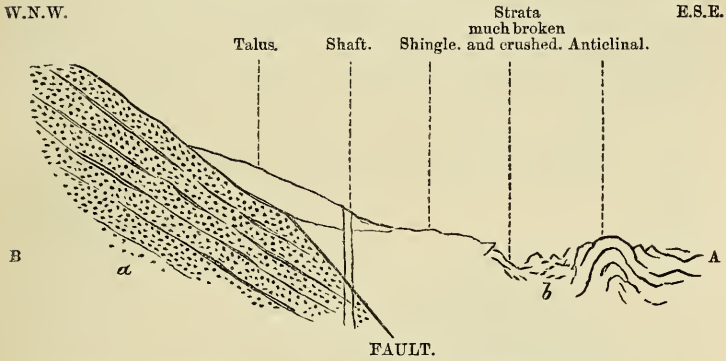


Fig. 9.—*Plan of the Reefs of Upper Oolite exposed in Eathie Bay, near Cromarty.*

entered the sandstones of the Old Red. The other pit was then

commenced further to the south and a little more removed from the line of junction, but still in close proximity to the great mountain-cliff of contorted Silurian rocks which form "the High land of Eathie;" it is said to have been carried to a depth of more than 100 feet in the shales and limestones of the Oolite.

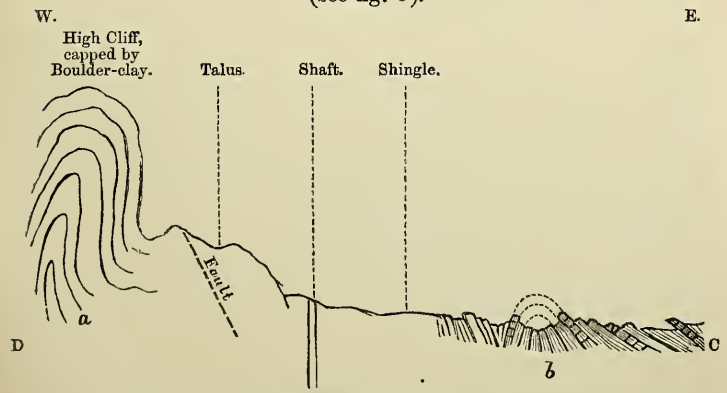
Fig. 10.—*Section at Eathie Bay along the line* A B *of the Plan* (see fig. 9).



a. Old Red Sandstone. *b*. Upper Oolite Shales and Grits.

A careful examination of the reefs on the Eathie shore, which dip at various high angles, and are often perfectly vertical, shows that

Fig. 11.—*Section at Eathie Bay, along the line* C D *of the Plan* (see fig. 9).



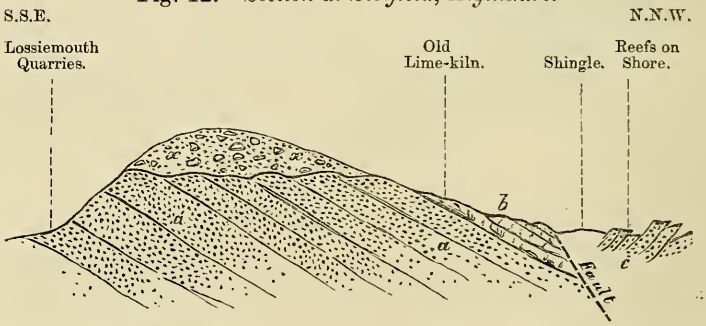
a. Lower Silurian Gneissose rocks &c.
b. Upper Oolite Shales, Limestones, &c., with pseudo-dykes.

they are the denuded edges of a series of strata bent into a number of sharp folds and contortions, as is illustrated in the sections,

figs. 10 and 11. The plan (fig. 9) shows the general relations of the strata exposed in Eathie Bay. At one point the rocks of the Upper Oolite, near their junction with the Old Red Sandstone, present the same crushed appearance that is so common, under similar circumstances, with the strata in Sutherland.

Crossing to the south side of the Moray Firth we find at Stotfield, in the county of Elgin, a patch of sandstone strata, to which my attention was first called by Dr. Gordon, and which has yielded to the patient researches of Mr. Grant, of Lossiemouth, a very considerable fauna. These beds, as will be shown in the sequel, are of Lower-Oolite age; and they are clearly seen to be faulted against the strata composed of calcareous and arenaceous rocks of Triassic age (see section fig. 12) *. It is possible that the whole of the reefs at this

Fig. 12.—*Section at Stotfield, Elginshire.*



x. Boulder-clay.
a. "Reptiliferous Sandstone." } Trias.
b. "Cherty rock of Stotfield." }
c. Greenish and reddish sandstones with shells (Lower Oolite).

point, and of the outlying rocks called Halliman Scars, are of the same age, and that their red colour is an accident due to similar causes to that which has produced the red colour of many of the reefs of Oolitic rock on the shore of Sutherland. These beds, however, have as yet yielded no fossils; and future researches may show that they are of a different age, and have been brought into their present position by another fault.

The promontory of Burghead is formed by a series of sandstones, grits, and conglomerates which, as Professor Harkness has well shown, is faulted against the great mass of the Reptiliferous sandstone † which forms the coast-ridge here. The similarity of position

* Since this paper was read, Prof. Ramsay has kindly intrusted to me the note-book used by him during his examination of the north of Scotland in 1859. It affords me no small satisfaction to find that in this, as in a number of other points, my own conclusions are entirely confirmed by the unpublished observations of my former teacher. Prof. Ramsay recognized the existence of a great fault at Stotfield, and represented it in a section identical in all essential points with my own.

† Quart. Journ. Geol. Soc. vol. xx. (1864) p. 436, fig. 3.

and relations of this patch to that of Stotfield, and the nature of the rocks which compose it, so greatly resembling the coarse grits and conglomerates of part of the unfossiliferous Lower Oolites of Sutherland, strongly suggest that the Burghead beds may be of the same age as those of Stotfield; but hitherto, unfortunately, no fossils have been found in the former.

At various points throughout the peninsula which lies between Burghead and Stotfield Heads, interesting strata of Triassic age are exposed, as will be described hereafter. The district is traversed by a series of great faults ranging N.N.E. and S.S.W., as shown by Professor Harkness *. By far the larger part of the area being deeply covered with drift, above which only a few ridges of the hardest rocks appear, it is possible that other patches of the Jurassic rocks may be preserved within it, though hidden from our observation; in the Boulder-clays of the district fragments and immense transported masses of the Liassic and Oolitic rocks are particularly abundant.

Having now described the general position and relations of the several patches of Secondary strata in the north-east of Scotland, it is necessary to refer to a peculiar phenomenon presented in them, and which has been already described by several geologists. I refer to the existence of *pseudo-dykes* among them. These present all the external forms of dykes of igneous rock, running in a more or less vertical direction across the several beds, and sending off various branches and offshoots in their course. When the nature of the rock of which they are composed is examined, however, it is found that, instead of being composed of materials of igneous origin, the rock is certainly an aqueous one, an indurated sandstone or a calcareous grit. These pseudo-dykes occur at Eathie †, Kintradwell ‡, and in the Brora coal-field §. Two important facts tending to elucidate this subject were noticed by Hay Cunningham and Hugh Miller respectively. The former showed that in the fine example at Kintradwell, fragments of carbonaceous matter occur, and that these are arranged, not horizontally as in the associated *beds*, but vertically and parallel to the sides of the dykes ‖; the latter found an Oolitic shell enclosed in one of the dykes at Eathie ¶. During my own survey of the district, the only fact of importance which I was able to add to those accumulated by previous observers was, that at Eathie some of the most important of these pseudo-dykes run along the axes of the anticlinal folds of the contorted strata.

These pseudo-dykes always traverse greatly disturbed or contorted strata. That they have been filled from above is clear, as pointed out by Hugh Strickland; but that the fissures in the soft

* Quart. Journ. Geol. Soc. vol. xx. (1864) p. 431, fig. 1.

† See H. E. Strickland in Trans. Geol. Soc. 2nd ser. vol. v. p. 599.

‡ Murchison, Trans. Geol. Soc. 2nd ser. vol. ii. p. 304. Cunningham, 'Geognosy of Sutherlandshire' (1839), p. 36, plate vii. fig. 2, note a.

§ Murchison, Trans. Geol. Soc. 2nd ser. vol. ii. pt. 2. p. 301.

‖ *Op. cit.* p. 36.

¶ Sketch-book of Popular Geology (1859), p. 305.

shales which they traverse could have remained open and been filled from the water of the sea which deposited the overlying rocks, like the Liassic veins in the Carboniferous limestone of the Mendips so admirably described by Mr. C. Moore *, seems altogether incredible. The explanation of the phenomenon which I would suggest is as follows:—that at the time when the upheaval which produced the fractures took place, the shales were already covered by beds of soft and unconsolidated sand, and that, as the fissures gradually opened, the sand as gradually found its way down into the interstices; finally the sand, both in the beds and the fissures, became consolidated into a hard rock.

§ 4. *Summary of Observations and Conclusions as to the Relations of the Palæozoic and Mesozoic strata of the North-east of Scotland.*

From the details which I have now given, I believe that the following propositions on the subject may be considered fully established.

(1) The Secondary rocks lie indifferently against all the members of the Lower Palæozoic series, from the Lower Silurian and associated granites up to the Upper Old Red Sandstone.

(2) The Secondary strata which are thus in contact with the Palæozoic rocks are of very various ages, from the Trias to the Upper Oolite inclusive, and contain representatives of all the subdivisions of the Jurassic series, except perhaps the Upper Lias.

(3) There is a total absence in the Jurassic series of strata made up of fragments of the rocks against which they repose; and, on the other hand, the conglomerates, which are by no means rare in that series, are made up of fragments of rocks totally different from these.

(4) There are no indications whatever in this series of Secondary strata that, as we approach the Palæozoic rocks, we are coming to an old shore-line.

(5) The Secondary rocks exhibit signs of having undergone great disturbance, being bent into numerous folds, broken up by many faults, and traversed by fissures filled with materials from above; their fossils are also much more frequently distorted by pressure than those of the equivalent strata in England.

(6) The evidence of disturbance and dislocation in the Secondary strata increases as we approach the Palæozoic rocks, till at last the beds of the former are often found in a completely crumpled and crushed condition at the points of contact.

All these facts point to one conclusion—namely, that the Secondary strata of the north-east of Scotland owe their present positions and their consequent remarkable preservation from the denudation which has removed such enormous masses of contemporary deposits in this area, to *great faults*, which have thrown them down, probably several thousands of feet, below their original level. I find that Prof. Geikie has already arrived at this conclusion with regard

* Quart. Journ. Geol. Soc. vol. xxiii. (1867) pp. 483, 491, &c.

to the patches in Ross *; and Prof. Ramsay informs me that, when he examined the Brora district some years ago, he was led to adopt the same views with regard to it.

§ 5. *Confirmations of the above conclusions concerning the Relations of the Palæozoic and Mesozoic Strata.*

I have now to point out two very remarkable and interesting phenomena, which, while they are on the one hand altogether anomalous and inexplicable, except on the hypothesis that the two series of rocks have acquired their present relations through the agency of great faults, are, on the other hand, seen to be in most complete harmony with the inferences to which all the other facts have led us.

It will be shown hereafter that the Upper Oolite beds in portions of this district are almost wholly made up of derived blocks. These blocks so precisely agree in mineral character with the Caithness Flagstones and associated beds of the Middle Old Red Sandstone, that Sir Roderick Murchison was evidently strongly inclined to refer them to this source. One fact, however, appeared to offer insuperable difficulties to accepting such a conclusion. The rocks which now appear in closest proximity to the Secondary strata in question are the Ord Granite, and the conglomerates and sandstones of the Lower Old Red, while the Middle Old Red Sandstones were then known only at a considerable distance. Sir Roderick pointed out the remarkable fact, which subsequent observations have completely confirmed, of the total absence of fragments of those well-marked and most easily recognizable rocks (the Ord Granite and the Old Red Conglomerate) in the "breeciated beds" †.

So fatal did Sir Roderick consider this fact to the hypothesis that the blocks in question were derived from the Palæozoic strata, that he found himself compelled to abandon it; but it is with evident doubt and reluctance that he resigns the theory in question in favour of another.

As I shall have to show more fully hereafter, the fact that these blocks in the "breeciated beds" are derived, and that they are of Middle Old Red Sandstone age, is put out of all question by the discovery in them of the remains of the characteristic fishes. The difficulty pointed out by Sir Roderick Murchison reappears therefore with its full force.

If, however, we admit that the present position and relations of the Primary and Secondary strata are due to a great fault, this startling difficulty at once disappears; for the thick series of the Middle Old Red Sandstone, so magnificently developed in Caithness, where it has escaped denudation, might then have formed the lands bounding the Oolitic sea, while the granite of the Ord and the conglomerates and sandstones of the Lower Old Red were buried below thousands of feet of newer rocks.

* Scenery of Scotland, p. 177.

† Trans. Geol. Soc. 2nd ser. vol. ii. pt. 2. pp. 306, 307.

Still more striking is the other phenomenon I have alluded to as confirming the existence of the great faults in question. As has already been pointed out, the highest mountains in the south-east of Sutherland are capped by the beds of the Lower Old Red Sandstone and Conglomerate, which, as we follow them towards the north, are found dipping under the enormously developed strata of calcareous and bituminous flagstones with associated sandstones, marls, &c. constituting the Middle Old Red Sandstone, and occupying so large a portion of the county of Caithness. Now no geologist can for a moment glance at the present relations of these strata without perceiving what Sir Roderick Murchison so clearly pointed out—namely, that the various patches of Old Red Conglomerate and Sandstone are the remaining vestiges of a widely spread formation which was doubtless once covered by deposits of Middle Old Red Sandstone age, forming the connexion between the great fish-bearing beds of Caithness and Ross *. Hitherto, however, not a trace of the Middle Old Red or Caithness Schists had been found in the county of Sutherland. During my examination of the district, I had the good fortune to discover a small but well-marked patch of these strata, the position of which was such as to be *absolutely inexplicable on any hypothesis but that of the existence of great faults*, and to afford the very strongest support, I may say the most triumphant confirmation, of those conclusions as to the relations of the strata which have been deduced from other facts.

The section which best illustrates the position and relations of the fragment of the Caithness flags referred to is exposed in the Allt-gharashtiemore (Gartymore Burn), north of the village of Port Gower; but other less complete sections enable us to trace the extent of this singularly isolated patch of the Middle Old Red Sandstone, and to show that it is about five miles long and from a quarter of a mile to half a mile broad. The accompanying section (fig. 13) clearly illustrates the relations of this wonderfully preserved fragment of a great formation. It is evidently enclosed between two great faults, by one of which it is brought into apposition with the granite of the Ord, which is probably of Lower Silurian date, while, by the other, strata of Upper Oolite age have been let down against it. The well-marked and highly distinctive characters of the beds of the Caithness Schist leave no room for doubt as to the correctness of the identification of the strata of this isolated patch. The Rev. J. M. Joass, who kindly examined this section with me, and whose intimate acquaintance with the Old Red Sandstone of the north of Scotland gives such weight to his opinion on the subject, informs me that he has not the slightest hesitation in considering them part of the Middle division of that formation, and that he has little doubt they belong to the lower part of that division. The strata, as might be expected from their position between the two great faults, are greatly disturbed and crumpled. They are seen again, but more

* *Vide* Murchison, Quart. Journ. Geol. Soc. vol. xv. (1859) p. 393 *et seq.*

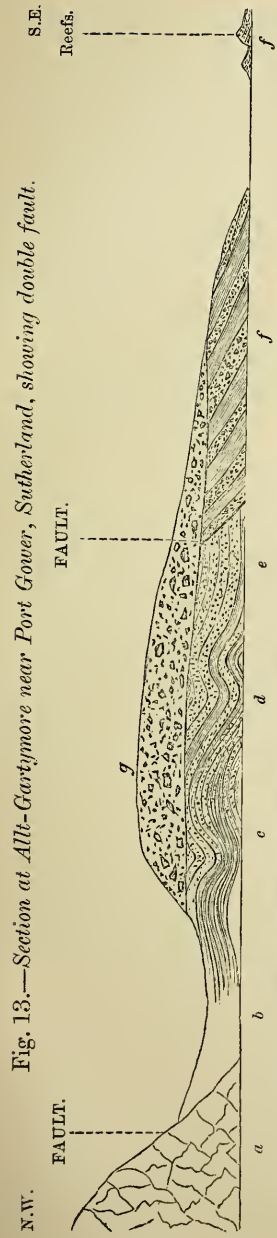


Fig. 13.—*Section at Allt-Gartymore near Port Gower, Sutherland, showing double fault.*

a. Granite of the Ord (Lower Silurian ?), capped in the interior by Lower Old Red Sandstone and Conglomerate.
b. Strata concealed.
c. Flaggy, calcareous, and highly micaceous beds.
d. Red and green argillaceous beds, with interstratified red and white mottled sandstone. } Old Red Sandstone, Middle Division (Caithness Flags).
e. Light-coloured sandstone, with pink spots and patches of greenish clay.
f. "Brecciated beds," alternating with finely laminated sandy clay, with lignites &c. (Upper Oolite).
g. Boulder-clay.

obscurely, in the gorges cut through the drifts by the Easter and Wester Garty Burns and the Lothbeg river*.

Here then we have proof that the great fault which has brought about the juxtaposition of the Primary and Secondary strata in Sutherland has, through about five miles of its course, become double, the strata on the south-east having been let down by two steps instead of one; and thus a strip of an intermediate formation has been preserved. Similar phenomena, on a smaller scale, are familiar to all field-geologists who have mapped greatly faulted districts.

We have thus shown that the preservation of the interesting patches of Secondary strata in the north-east of Scotland is entirely due to the concurrence of a series of favourable accidents. First among these (both in order of time and in importance) we must rank those great dislocations which have brought the strata in question into apposition with rocks of so much greater hardness and capability of resisting denuding forces. The general strike of these great faults is from N.E. to S.W.; and they doubtless constitute a portion of the results of that great and long-continued series of disturbances which have so largely contributed to the production of the physical features of this island. The influence of this great

* Since my return to England, my indefatigable friend Mr. Joass informs

system of subterranean disturbance is seen, not only in the general parallelism of the great synclinal and anticlinal folds and the faults of the strata in Scotland, and the consequent position and features of her mountain-ranges, valleys, rivers, and lochs, together with the outlines of her coasts and islands, but equally in the direction of the strike of the outcrops of the long series of successive geological formations in England. The facts of the existence and long continuance of this great system of disturbance, and the important results produced by it, are now admitted by all geologists, whether they regard such subterranean forces, with the late Sir Roderick Murchison and the Duke of Argyll, as the *immediate* cause of the physical features of the country, or, with Professors Ramsay and Geikie *, as only directing and modifying the really efficient and direct cause of those phenomena—namely denudation.

A review of the general position and relations of the strata of the north-east of Scotland appears to indicate that, over the tract now occupied by the Moray Firth, the Secondary strata were let down among the Palæozoic rocks by a series of parallel faults ranging N.E. and S.W., and that, by the slow action of denuding forces, the great mass of these strata has been removed, a few minute patches alone escaping. The general form of this vast inlet and the position of the peninsulas which project into it have been determined by these great faults; and it is probable that extensive deposits of Secondary age still exist beneath its comparatively shallow waters.

To some the hypothesis contained in the foregoing pages may, at first sight, appear startling—namely that, over large areas of the Highlands, Secondary strata to the thickness of from 2000 to 3000 feet (not to notice the Cretaceous and Triassic rocks) once existed, and that all of these, with the exception of a few minute fragments, have been removed by denudation. But those who have seen how many thousands of feet of apparently almost imperishable rocks, like the Laurentian gneiss, the Lower Silurian quartzites, and the Old Red conglomerates, have evidently been removed over vast areas in the Highlands, as indicated by the truncation of curved strata and the position of outlying patches, will readily admit the facility with which the same causes, under equally favourable conditions, would have swept away the comparatively soft masses composing the strata of the Secondary series.

III. *Description of the Series of Secondary Formations in the North-east of Scotland.*

An admirable topographical description of the areas occupied by

me that a portion of a *Coccosteus*, a characteristic fish of the Middle Old Red, has recently been obtained from this isolated patch in Sutherland.

* Professor Geikie considers that the fault which has thrown down the patches of Oolite on the Ross-shire coast may be only a continuation of that great dislocation which certainly traverses the line of the Caledonian Canal ('Scenery of Scotland,' p. 177); if not continuous with, it is certainly parallel to, that great fault.

the Mesozoic strata in the north-east of Scotland having been already given by the late Sir Roderick Murchison, and the important question of the relation of these strata to the Primary rocks fully discussed in the foregoing pages, we may now proceed to a detailed account of the characters presented by each of the Secondary formations as developed in this district. These we shall treat of in chronological order. With regard to the sequence, mineralogical characters, and fossils of the subdivisions of the Mesozoic strata we have three kinds of evidence, which are of very different degrees of value.

1st. The connected series of sections, sufficiently clear though often of limited extent, of the beds seen *in situ* in Sutherland (see Table I.).

2nd. The sections in the more isolated patches, also *in situ*, at other points around the shores of the Moray Firth.

3rd. The large transported blocks and numerous scattered fragments of the various Secondary rocks included in the Boulder-clay of this part of Scotland (see Table II.).

§ 1. *The Trias.*

On the southern side of the Moray Firth, between the headlands of Burghead and Stotfield, a tract of land projects considerably to the northward of the general line of the coast; at a period geologically very recent, part of this district constituted an island in the Firth, and till late historical times it remained almost separated from the mainland of Scotland by the Loch of Spynie. Within this promontory and in the country bounding it on the south there is developed a formation which, on account of the apparent discrepancy between the stratigraphical and palæontological evidence as to its age, has attracted much attention and occasioned keen debate among geologists. Under these circumstances, it may be advantageous to distinguish carefully between the conclusions (concerning the relation of these beds) which are the result of direct observation, and therefore not open to question, and such as have been arrived at from inferences of a general character and are still the subjects of controversy.

The formation in question consists of two members, the upper calcareous, the lower arenaceous.

A. "*The Cherty Rock of Stotfield.*"—Great differences of opinion have existed among geologists as to the correct designation for this rock. Sir Roderick Murchison calls it a "cornstone," but at the same time points out that it presents characters which distinguish it from the rocks usually included under that name*. Professor Harkness discards the use of the term "cornstone" and calls it simply a limestone†; while the Rev. W. S. Symonds strongly insists that "cornstone," as applied to this rock‡, is altogether a misnomer, and Mr. C. Moore compares the rock to one which occurs

* Quart. Journ. Geol. Soc. vol. xv. (1859) p. 431.
† Ibid. vol. xx. (1864) p. 431 &c.
‡ Edinburgh Phil. Journ. New Ser. vol. xii. (1860) p. 96.

in the Trias on the flanks of the Mendips *. All observers, however, agree that the rock is of a remarkably peculiar and almost *unique* character, Mr. Symonds calling it "*a most distinguishable rock*." To obviate confusion, I use a term which does not involve any theoretical views, and which was first applied to it by Dr. Gordon of Birnie †, who has done so much for the elucidation of the geology of this difficult district, both by his own observations and by constantly placing his great local knowledge at the service of other investigators.

The mass of the Stotfield rock is composed principally of calcareous and siliceous materials. The former is usually a hard, compact, impure limestone, of a cream-colour, which in places becomes crystallized and exhibits fine examples of calc-spar, with fibrous and radiated carbonate of lime. The latter forms nodules and cavernous masses imbedded in the former, and consists of compact cherty or flinty material, occasionally exhibiting the banded structure of jaspers and agates, and containing drusy cavities incrusted with crystals of quartz or mammillated coatings of chalcedony. With these principal materials there is often associated an amorphous argillaceous mineral, of a greenish colour; while beautifully crystallized galena, pyrites, and blende are sometimes disseminated through the mass as accidental ingredients.

The total thickness of this rock is unknown, its upper portion being always denuded away; but it is said to have been dug to the depth of 30 feet ‡. When exposed to weathering action, the calcareous portion of the rock is removed, and the hard indestructible masses of cherty material remain. Where the rock is covered with Boulder-clay, pits were formerly dug into it; and the most purely calcareous masses being selected, they were burned into lime; but the tendency of the material, when the siliceous portions were not rigidly excluded, to fuse into solid masses in the kiln, and the superiority of the Silurian limestones of Banffshire, have led to the almost total abandonment of these old pits. Several attempts have been made at Stotfield to work the galena, which is associated with this rock there, as also at Inverugie and other points; but, owing to the fact of the metallic ores being disseminated through the mass and not collected into veins, these attempts have proved futile.

The origin of this peculiar rock, *which is altogether destitute of any trace of organic remains*, is a very interesting problem. That its formation must be referred to purely chemical agencies is, I think, in the highest degree probable; but into this question I do not propose to enter, it being sufficient for my present purpose to point out the highly peculiar, if not unique, character of the rock, and the consequent facility with which it can be identified.

B. "*The Reptiliferous Sandstone.*"—This lower division of the formation consists of beds of sandstone, sometimes slightly calcareous, and usually of a pale colour inclining to yellow; it has often grains

* Quart. Journ. Geol. Soc. vol. xvi. (1860) p. 446.

† Edin. New Phil. Journ. New Ser. vol. ix. (1859) p. 15.

‡ Duff, 'Sketch of the Geology of Moray' (1842), p. 23.

of a dark material disseminated through it. Locally, as is so commonly the case with rocks coloured by oxide of iron, it exhibits patches of a pinkish tint. In these sandstones false-bedding abounds, while the true bedding is often very indistinct; the jointing, on the other hand, is usually extremely well-defined; and the combination of these characters gives the rock a peculiar and distinctive mode of weathering, as was pointed out to me by my friend Dr. Gordon.

This rock is almost wholly destitute of organic remains; but at certain points, especially in some of the extensive quarries near Cummingstown, its bedding-planes exhibit ripple-marks, sun-cracks, and tracks of various kinds, including numerous series of foot-prints of very various size and character. At Lossiemouth there is a bed, about 100 feet below the top of the sandstones, which has yielded numerous scales and bones of the reptiles *Stagonolepis*, *Hyperodapedon*, and *Telerpeton*, while of the last-mentioned genus a single specimen (the original one) has been found at Spynie, and some remains of the first-mentioned have occurred at Findrassie. It is a singular and noteworthy circumstance that the foot-prints and reptilian remains are never found together; and in only one instance have they been obtained from the same quarry.

This sandstone rock is very extensively quarried about Cummingstown, Hopeman, Lossiemouth, and Spynie; and most of its beds yield a very valuable freestone, of excellent colour, which can be obtained in blocks of great size. It forms, indeed, one of the principal building-stones of the north of Scotland, and, the quarries being contiguous to the sea, it is exported to considerable distances.

Unfortunately the stratigraphical relations of the formation which we have been describing are almost wholly concealed by the enormous masses of Boulder-clay and other superficial accumulations which prevail to so great an extent in this district. Dr. Gordon, writing in 1859, says—

"Two circumstances tend materially to render the examination of this part of the province of Moray difficult to the geologist. There are such vast accumulations of the Boulder-clay, of the gravels and sandbanks of the drift, and of the débris of ancient sea-margins, that few sections of the underlying strata are fully exposed; and even where they are best seen, there seems to have been so great and so extensive a denudation during the time of their deposition, that a complete or uninterrupted sequence of strata and their beds has not been detected" *.

An admirable description of these various superficial deposits has been given by Mr. John Martin, of Elgin†.

The relation of the calcareous and arenaceous members of the formation we are describing is fortunately perfectly clear; and, indeed, this point has never been disputed. At Stotfield and Inverugie the peculiar calcareous and cherty rock is seen to overlie and pass down into the Reptiliferous Sandstone; and the position of the same strata

* Edin. New Phil. Journ. New Ser. vol. ix. (1859) p. 15.
† Ibid. New Ser. vol. iv. (1856) p. 209.

at Spynie * and other points at which they are seen is such as entirely to harmonize with and confirm this conclusion.

When, however, we seek for information as to the strata which respectively underlie and succeed this formation, we find that the greatest differences of opinion prevail. Nowhere in Elginshire has the Cherty Rock of Stotfield been seen to be covered by any other beds; indeed it is the remarkable indestructibility of that stratum which, as pointed out by Sir Roderick Murchison, has led to the preservation of the several ridges of sandstone, which rise like islands in the midst of a sea of drift. Whenever it is well exposed, as at Inverugie and Linksfield, the upper surface of the Cherty Rock of Stotfield exhibits the most beautiful glacial polishing and striation. The fact that this rock is never found succeeded by any other formation in the Elgin district has been very strongly insisted upon by several authors, especially by Mr. Duff† and Professor Harkness‡.

Similarly we seek in vain for any clear and undisputed section showing the Reptiliferous Sandstone in overlying contact with any other rock.

As the several exposures of the various rocks in the Elgin district are often miles distant from one another, and the inclination of the beds considerable, views of the most diverse character have been maintained by different geologists as to the relations of the different rocks underlying the drifts in this district, even when they agree in regard to the primary question of their age. In illustration of this it is only necessary to point to the sections of Sir R. I. Murchison§ and Professor Harkness‖ taken along the same line of country.

The rocks which in the Elgin district are developed in the immediate neighbourhood of the disputed formation are proved by the most unquestionable evidence to belong to the Old-Red-Sandstone system; and from the general positions, relations, and dips of the several patches of rock exposed, we should be led to conclude that the strata in question belonged, *if the country were not a greatly faulted one*, to that system.

In support of this view it has been pointed out that in the higher division of the Old Red Sandstone there exist light-coloured arenaceous strata, not very dissimilar in character to the Reptiliferous Sandstone; while the Cherty Rock of Stotfield has been thought comparable to some of those concretionary limestones or cornstones which are not unfrequently found in the Old Red.

On the other hand it is a remarkable fact that, while in almost every quarry opened in these higher beds of the Old Red Sandstone remains, more or less numerous, have been found of the characteristic fishes of that system, the Reptiliferous Sandstone, which has

* See Captain Brickenden's Paper, Quart. Journ. Geol. Soc. vol. vii. (1853) p. 289.

† Sketch of the Geology of Moray (1842), p. 24.

‡ Quart. Journ. Geol. Soc. vol. xx. (1864) pp. 433, 435, 436, &c.

§ Ibid. vol. xv. (1859) pp. 424–428, figs. 1 and 2.

‖ Ibid. vol. xx. (1864) p. 431, fig. 1.

been worked on a very extensive scale, and subjected to the most diligent search, has never yielded a trace of such fossils. Neither has any trace of the reptilian scales or bones been found in any undoubtedly Old Red Sandstone beds. The Cherty Rock of Stotfield, too, is admitted on all hands to differ greatly from any recognized bed of cornstone, and strikingly from that which occurs in the immediate neighbourhood at Foths in the parish of Birnie, and which is of undoubted Old-Red-Sandstone age.

But in a district which is so hopelessly sealed up from the investigations of the field-geologist by overwhelming masses of drift as is that of Elgin, the generalizations founded on the examination of a few exposures of rock, miles apart, lose all their weight, if it should appear that the country has been subjected to great dislocations.

That the strata of the Elgin district have been thus broken up by a series of fractures is, I think, quite indisputable. Indeed I believe that no one acquainted with the area will deny the existence of a number of great faults ranging E.N.E. and W.S.W., and of cross fractures subordinate to these. In proof of this disturbed condition of the strata I would briefly notice the following circumstances.

1. The strata, when examined over the whole district, are found to dip at various angles, and at some points, as the Clashack quarry, are actually seen to be bent into great anticlinal folds.

2. Even in the small exposures of the strata visible, as between Burghead and Cummingstown and on the Findhorn, as pointed out by Professor Harkness*, and near Bishop-Mill as pointed out by Mr. Symonds†, there are indications of the existence of faults.

3. The repetition of strata which are unquestionably the same and have a considerable dip, at distant points (as for example, in the Spynie and Lossiemouth ridges, which are three miles apart), indicates the existence of such disturbance.

4. I may notice that Professor Harkness has pointed out the existence of these great lines of faulting, and has indicated their probable position.

5. Dr. Gordon has noticed the existence of patches of Old Red Sandstone lying at Pluscarden and Rininver in the midst of the Lower Silurian strata‡, identified in the former locality by the remains of fish, and in both by the marked mineral characters of the beds; and it seems to be impossible to account for the position of these except by admitting that the whole district has been subjected to great dislocation.

Lastly, I have shown that strata, proved by the most unquestionable fossil evidence to be of as recent date as the Lower Oolite, are found at Stotfield faulted against the older strata. The existence of this fault was recognized by Professor Ramsay in 1859.

The conclusion, to which I think all the facts which I have ad-

* Quart. Journ. Geol. Soc. vol. xx. (1864) p. 432, fig. 2, p. 436, fig. 3.
† Edin. New Phil. Journ. New Ser. vol. xii. (1860) p. 97.
‡ Ibid. New Ser. vol. ix. (1859) p. 43.

duced point, is that *in the Elgin district* the formation, which is made up of the two well-marked members the Cherty Rock of Stotfield and the Reptiliferous Sandstone, is altogether *isolated*, and its stratigraphical relations therefore *undeterminable*. I believe that I am supported in this conclusion by those who have made this district the subject of their most constant and careful study.

Under these circumstances a question of great importance arises—namely, whether this remarkable formation exists in any other district, where its relations may be the subject of more successful investigation by the geologist.

The beautiful Ross-shire section of the Old Red Sandstone, which exhibits in a series of cliff-exposures a conformable succession of beds, from the lower conglomerates of the Northern Sutor of Cromarty to the light-coloured sandstone of Tarbet Ness, has been described by Professor Sedgwick and Sir R. I. Murchison*, the Rev. J. M. Joass†, and Professor Harkness‡. The supposition originally put forward by Sir R. I. Murchison, that the highest beds of this section represent the Reptiliferous Sandstone of Elgin, appeared to derive great support from the interesting discovery of footprints in these strata at Portmahomack and Cambus Shandwick, which discovery was made in 1863 by the Rev. J. M. Joass and the Rev. George Campbell§.

But, in spite of this most valuable discovery, I cannot but regard this identification of the strata of Tarbet Ness with the Reptiliferous Sandstone as a very doubtful one. In mineral character the former much more closely resemble the light-coloured sandstones of Upper-Old-Red age both in Elginshire and Sutherland. Too much weight must not be attached to the presence of *footprints*, which might, indeed, have been occasioned by *Amphibians* such as we now know to have existed at as remote a period as that of the Lower Carboniferous. Professor Elliot some years ago discovered what were supposed to be footprints in the undoubted Upper Old Red Sandstone beds of Nairnshire. This circumstance was brought under my notice by Dr. Gordon, to whom I am indebted for so much assistance in the study of this question. The slab on which these markings are seen was presented by Mr. Stables, of Cawdor, to the Elgin Museum; but, from examination of a cast of them, both Professor Huxley and Professor Rupert Jones pronounce these markings to be of exceedingly doubtful origin.

The strongest circumstance, however, against the identification of the Tarbet-Ness sandstones with those of Elgin is the absence at the former place of that most remarkable, indestructible, and easily recognizable stratum, the Cherty Rock of Stotfield. When we consider the manner in which the two members of the formation are always associated in Elginshire, and the fact that the preservation of the sandstones from denudation appears to be in

* Trans. Geol. Soc. 2nd Ser. vol. iii. part i.
† Quart. Journ. Geol. Soc. vol. xix. (1863) p. 506.
‡ Ibid. vol. xx. (1864) p. 437.
§ Ibid. vol. xix. (1863) p. 506.

every instance due to the indestructibility of the overlying cherty rock, the absence of this latter in Ross-shire becomes the more inexplicable. No importance can be attached to the fact which has been pointed out that fragments of the rock are found on the beach near Tarbet Ness, as, owing to their intense hardness, similar rolled fragments are common all round the shores of the Moray Firth.

Although we may reject the evidence of the footprints of Tarbet Ness as supporting the identification of the sandstones of that place with the reptiliferous beds of Elginshire, yet the great interest and importance of the discovery remains. Indeed that interest is greatly heightened if, by the separation of them from the Reptiliferous Sandstone of Elginshire, we are able to remove all reasons for doubting their Old-Red age; for we may, in that case, regard it as proved that beings *higher in the animal series than fishes* existed at as early a period as that of the Upper Old Red Sandstone.

The difficulties in which, as we have seen, the question of the relations of this remarkable formation is involved on the southern side of the Moray Firth disappear, I believe, when we examine it on the northern side of the same Firth. In the county of Sutherland, at a distance of 30 miles from Stotfield, both the members of the formation occur; and the sections, fortunately, are of such a clear character that, while on the one hand they satisfy the observer as to the identity of the rocks on the north with those on the south of the Firth, they, on the other hand, leave no room for doubt as to the true position of these rocks in the geological series.

I am indebted to the Rev. J. M. Joass for first calling my attention to some patches of a peculiar rock imperfectly exposed in the Burn of Golspie. Subsequent study of the district enabled me to trace this rock, partly by small exposures and partly by the exact records of the position of old lime-pits &c. in Farey's Report on the district (to which I have already alluded), through its outcrop of nearly two miles in length to the reefs on the shore between Golspie and Dunrobin, where its relation to the series of Secondary strata is perfectly evident. A careful examination and comparison of the rocks on both sides of the Moray Firth convinced me that this rock was no other than the Cherty Rock of Stotfield, and that it was underlain by a series of sandstones with similar characters to those of the reptiliferous beds of Elgin. My friend Dr. Gordon has since informed me that some years ago, on being shown the isolated patches of rock in the Golspie Burn (concerning the relations of which nothing was at that time known), he at once pronounced them to be identical in character with his "Cherty Rock of Stotfield."

I have already pointed out the highly distinctive characters of this remarkable rock, which characters are exhibited in the most striking manner by the Sutherland deposit. We have the same peculiar cream-coloured limestone, occasionally crystallized, with like irregular cherty nodules, the whole mingled with the same greenish argillaceous mineral. Indeed, when we compare a series of specimens obtained on the northern side of the Firth with one from the southern side, the rocks are found to be absolutely undistinguish-

able. As in Elginshire, the rock near Golspie was formerly burnt for lime; and its use has been abandoned for the same reasons as in that county. The points in Sutherland where the Cherty Rock of Stotfield has occurred are as follows:—

In a wood N.N.E. of Rhives House, where it was dug and burnt (*Farey*). The pit is now abandoned.

In the romantic Glen of Dunrobin, by the side of the Golspie Burn, there are two exposures of the rock, the strata evidently having resisted denudation, as in the neighbourhood of Elgin, and appearing under a great mass of superincumbent Boulder-clay. The more northerly of these exposures exhibits the highly calcareous variety of the rock, perhaps forming its upper part, while at the southern point the rock is more siliceous.

In the excavations about the Golspie Bridge, and in digging the foundations of the Golspie Inn, the same rock was met with (*Farey*).

In the bank south-west of Dunrobin Castle, in what is known as the Quarry Park, there is an old pit where the rock was formerly dug for lime-burning and for marl, and where its characters can be still examined. Here, as in Dunrobin Glen, we find the most complete agreement between this rock and the well-marked Cherty Rock of Stotfield.

Lastly, the rock can be traced running out to sea in the reefs between Dunrobin and Golspie. Here the calcareous portions are dissolved away, and the cavernous masses of cherty material are seen, identical in every respect with the similar weathered masses of Stotfield shore and Spynie Hill.

These last hard masses of chert have been the means of preserving the sandstones below from destruction by denudation, in the same manner as we have seen to be the case in Elginshire. The thickness of sandstone exposed is not great, probably not more than 40 or 50 feet; but the similarity of the rock in colour, texture, and mode of weathering to the Reptiliferous Sandstone is most striking. It is true that these sandstones have not yielded any reptilian remains, or, indeed, any kind of fossils; but it must be remembered that the sandstones of Elginshire are equally barren to much greater depths, all the fossils having been obtained from one bed, which is at a lower horizon than any part of the series exposed in Sutherland. The fucus-covered and rarely accessible reefs of the latter county also afford no such facilities for the detection of fossils as are presented by the extensive quarries of Elginshire. The Dunrobin reefs can only be seen at low water; and, indeed, it is only during spring tides that a satisfactory examination can be made of the lowest of them.

It is, I believe, impossible for any one to examine these rocks on the north and south side of the Moray Firth respectively, especially bearing in mind the *unique* features presented by the higher and calcareous beds, without being fully convinced of their complete identity.

The relations of these strata are, as already intimated, perfectly clear in the county of Sutherland, and they are such as to con-

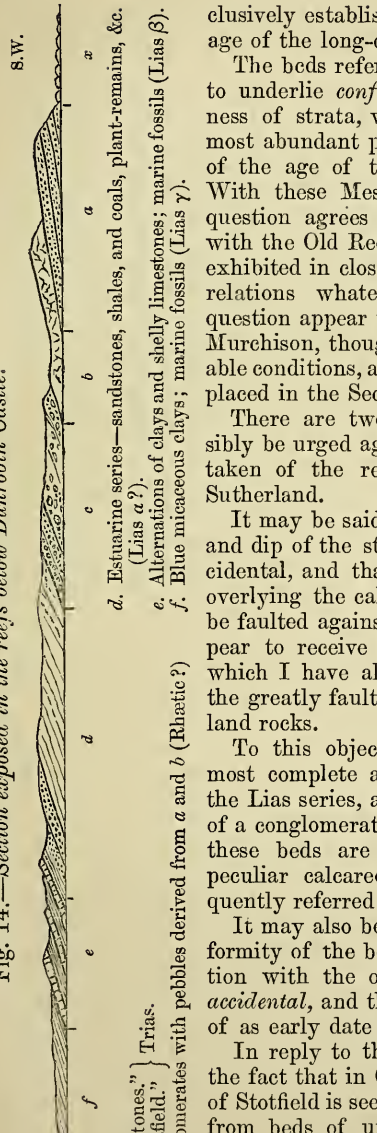


Fig. 14.—*Section exposed in the reefs below Dunrobin Castle.*

x, *x*. Shingle.
a. "Reptiliferous Sandstones." } Trias.
b. "Cherty Rock of Stotfield." }
c. Sandstones and conglomerates with pebbles derived from *a* and *b* (Rhætic?)
d. Estuarine series—sandstones, shales, and coals, plant-remains, &c. (Lias *α*?).
e. Alternations of clays and shelly limestones; marine fossils (Lias *β*).
f. Blue micaceous clays; marine fossils (Lias *γ*).

clusively establish, as I believe, the Secondary age of the long-disputed beds (fig. 14).

The beds referred to are seen at Dunrobin to underlie *conformably* a considerable thickness of strata, which I shall demonstrate by most abundant palæontological evidence to be of the age of the Middle and Lower Lias. With these Mesozoic strata the formation in question agrees both in strike and dip, while with the Old Red Sandstone strata, which are exhibited in close proximity, it has no common relations whatever. Indeed, the strata in question appear to have been seen by Sir R. I. Murchison, though probably not under favourable conditions, and were by him unhesitatingly placed in the Secondary series.

There are two objections which may possibly be urged against the view which I have taken of the relations of this formation in Sutherland.

It may be said that the agreement in strike and dip of the strata at Dunrobin may be accidental, and that the Lias strata, instead of overlying the calcareous and cherty rock, may be faulted against it. This objection may appear to receive some support from the facts which I have already pointed out, indicating the greatly faulted condition of these Sutherland rocks.

To this objection there is fortunately the most complete answer. The lowest beds of the Lias series, as is so often the case, consist of a conglomerate; and among the pebbles in these beds are numerous fragments of the peculiar calcareous and cherty rock so frequently referred to.

It may also be urged that possibly the conformity of the beds of the formation in question with the overlying Lias strata may be *accidental*, and that in spite of it they may be of as early date as the Old Red Sandstone.

In reply to this objection I would point to the fact that in Golspie Burn the Cherty Rock of Stotfield is seen at only a very short distance from beds of undoubted Old Red Sandstone strata, and that while the latter are greatly disturbed and dip S.E., at an angle of 70°, the former dips N.N.E. 12°, conformably to the great mass of Secondary strata here.

The facts now adduced with regard to the stratigraphical relations of the "Cherty Rock of Stotfield" and the underlying sandstone (which we cannot hesitate to recognize as the

Reptiliferous Sandstone) in the county of Sutherland are such as to prove that these strata are of Secondary age, and that they are older than the Lower Lias.

I have argued this question hitherto mainly on stratigraphical grounds, and have shown that there would be the strongest reasons for believing the formation in question to be of Secondary age, even if there were a total absence of all palæontological evidence.

But this is very far from being the case. The interesting descriptions of *Stagonolepis*, *Telerpeton*, and *Hyperodapedon* by Professor Huxley, and his discussion of their bearing on the age of the Reptiliferous Sandstones of Elgin are too fresh in the minds of all geologists to need recapitulation here. In 1858 Professor Huxley declared* that the palæontological evidence in favour of the Secondary age of the reptiles was so weighty as to "lead one to require the strongest stratigraphical proof before admitting the palæozoic age of the beds in which they occur." Since that date he has, as every one is aware, greatly strengthened that palæontological evidence by demonstrating that, alike in Warwickshire, Devonshire, and India, *Hyperodapedon* occurs in beds of Triassic age†.

Thus we find that the stratigraphical and the palæontological evidence with regard to this interesting formation in the north-east of Scotland are in complete accord, and we are justified in regarding it as of undoubted Triassic age—a fact which is of the greater interest from the circumstance that strata of that period are of such rare occurrence in Scotland.

Sir Roderick Murchison has suggested that, if the Reptiliferous Sandstones are to be referred to the Trias, they must in all probability be considered as representing the Keuper sandstones‡. In that case it may be consistent to place the "Cherty Rock of Stotfield" on the horizon of the lower part of the New Red marls. The partial break indicated by the overlying conglomerate beds, unattended as it is by any difference of dip, would be perfectly consistent with the absence of the higher portions of the Keuper series.

It was also pointed out by Sir Roderick§ that there might be in Elginshire and Ross-shire an *accidental* conformity between beds differing as greatly in age as the Trias and Upper Old Red, and that on this supposition the apparent anomalies presented by the district might be accounted for. From a careful examination, however, of the whole question of the relations of the Primary and Secondary rocks around the Moray Firth, I am led to infer that the true key to the enigma presented by the Elginshire rocks is to be found in the great faults which certainly traverse the whole of the district, and as certainly have been the cause of even more striking phenomena in other parts of it.

There are good reasons for believing that these Triassic strata of the north-east of Scotland are, like those of England (as has been

* Quart. Journ. Geol. Soc. vol. xv. (1859) p. 460.
† Ibid. vol. xxv. (1869) p. 138.
‡ Siluria, 5th edit. (1867) pp. 267, 268.
§ Ibid.

argued by Professor Ramsay, Mr. Godwin-Austen and others), of lacustrine origin,—a conclusion supported by the paucity of organic remains in them, and the peculiar characters of the rock which forms their upper member.

§ 2. *The Rhætic?*

At the base of the Liassic series of strata in Sutherland, and immediately overlying the formation just described, there occurs a series of coarse sandstones with beds of conglomerate (fig. 14, *c*, page 143). As has been already pointed out, the pebbles in this conglomerate are not derived from the Old Red Sandstone or any other Palæozoic rock, but in part at least, from the sandstones and cherty limestones of the Trias. The base of the Lias in Scotland, as in South Wales and many parts of France and Germany, is usually formed by similar conglomerates; but on the Western Coast the Secondary rocks generally repose unconformably on the older Palæozoic strata, such as the Silurian and Cambrian, and the conglomerates are made up of pebbles of those rocks.

These conglomerates and sandstones of Sutherland, which attain a considerable thickness, but are somewhat imperfectly exposed, have not exhibited any trace of those bone-beds sometimes found in equivalent strata; nor, indeed, have they yielded any kind of fossil remains whatever. As indicating the slight oscillations of level, insufficient to produce unconformity, which marked the gradual transition from the Trias to the Lias, we may, with a strong show of probability, consider them to be of Rhætic age. They are evidently a littoral deposit, and are overlain by, and graduate up into the series of estuarine strata constituting the base of the Lower Lias.

On the opposite or southern side of the Moray Firth there are a number of masses of strata, not *in situ*, but included in the Boulder-clay, which from their mineral characters have been variously referred by different authors to the Wealden, Purbeck, and Rhætic. I have already pointed out how little weight should be attached to mere mineral characters in the determination of the age of the Secondary strata of Scotland; and as the masses in question are completely isolated in the drift, we are reduced to the purely palæontological evidence.

The most important of these masses is that of Linksfield, which was first brought under the notice of geologists by Dr. Gordon in 1832*. The peculiarities of the strata here were found by Dr. Malcolmson to be such as to lead him, in the year 1838†, to suggest that they were the equivalents of the Wealden or Purbeck—a view that was adopted by Mr. Duff, Mr. Robertson and other observers‡. On the other hand, Mr. C. Moore§, in the year 1859, pointed out the striking resemblances in the mineral characters and succession of

* Proc. Geol. Soc. vol. i. p. 394. † Ibid. vol. ii. p. 667.

‡ Sketch of the Geology of Moray, 1842; Anderson's 'Guide to the Highlands,' 3rd edition (1851); &c.

§ Brit. Assoc. Rept. (1859) p. 264. Quart. Journ. Geol. Soc. vol. xvi (1860) p. 445.

the beds at Linksfield to those of the Rhætic formation in the south-west of England, and he showed that there exists some palæontological evidence in favour of identifying the two series. In this view he was confirmed by Professor Rupert Jones*.

The remarkable position of the mass of Secondary strata at Linksfield has given rise to a number of hypotheses to account for it. The chief of these are as follows:—

(1) That the stratified clays and limestones once rested immediately upon the Triassic limestone, and that the foot of a glacier or iceberg forced the two sets of strata asunder, carrying with it a mass of glacial detritus and scoring and polishing the hard surface of the lower rock. This hypothesis appears to have been first suggested by Mr. A. Robertson, of Inverugie, and Captain Brickenden †, and to have received the sanction of Professor Agassiz.

(2) The hypothesis suggested by Sir Charles Lyell at the Aberdeen Meeting of the British Association (1859) is as follows:—"That a range of cliffs, of Triassic and Lower Liassic beds, rose above the Vale of Elgin during the glacial epoch, when ice rafts and drifting bergs, with all the phenomena of an Arctic sea, swept down that vale, then a frith, and that the siliceous cornstone was then the actual sea-bed. The icebergs and drifting masses undermined the soft marls of the Upper Trias and Lias, and in time produced a landslip. The whole side of a sea-cliff slipped down from its position, on to a beach of Boulder-clay, without any bouleversement of the strata"‡.

(3) The view first put forward by Dr. Gordon§ and other local observers, and since advocated by Professors Geikie and Ramsay‖, is, that the mass of Linksfield and similar masses in the neighbourhood are really great transported blocks, which have been carried by ice across the sea in which the Boulder-clay was formed, and quietly deposited at the bottom by the stranding and gradual melting of the ice rafts.

The results of the more careful and exact studies of the modes of ice-action made during recent years have been such as, I believe, to lend but little support to the first of these hypotheses, while on the contrary they have, by furnishing undoubted examples of analogous action and by showing the futility of supposed objections, removed many of the difficulties which prevented the acceptance of either of the two other hypotheses.

The preservation of a mass of strata, higher in the series than the

* Monograph of the Fossil Estheriæ (Palæontographical Society, 1862), pp. 74–77.

† Quart. Journ. Geol. Soc. vol. vii. (1851) p. 291 See also A. Robertson, in Anderson's 'Guide to the Highlands,' 3rd ed. (1851) p. 344; a similar view appears to have been hinted at by Mr. Duff, 'Sketch of the Geology of Moray' (1842).

‡ Symonds in Edin. New Phil. Journ. New Ser. vol. xii. (1860) p. 100, and Quart. Journ. Geol. Soc. vol. xvi. (1860) p. 459.

§ Edin. New Phil. Journ. New Ser. vol. ix. (1859) p. 52. Ibid. vol. iv. (1856) p. 223.

‖ Quart. Journ. Geol. Soc. vol. xxvii. (1871) p. 252.

beds in the immediate neighbourhood, through being let down by faults, is a phenomenon familiar to every geologist, and, indeed, is illustrated by wonderful examples cited in the present memoir. That landslips acting during the Glacial epoch might have produced a similar result on a small scale is clear; and, indeed, examples of the kind have presented themselves to me during my survey of districts thickly covered with drift in the Midland counties of England*. I have already shown reasons for believing that the Secondary strata were largely developed in the Elgin district.

On the other hand, the principal objection which has been raised to the hypothesis that the Linksfield mass is a boulder†, namely that of its great size, has been effectually disposed of by the discovery of undoubted transported masses of equal, and even greater dimensions, imbedded in the Boulder-clay of other districts‡.

It is not my purpose to attempt to decide between these two hypotheses, both of which appear to harmonize equally well with all the phenomena of the case—the glacially striated and polished rock at the bottom of the section, the overlying and underlying Boulder-clay, containing detached fragments of the same beds, and sometimes filling fissures in the principal mass, and the contorted, cracked, and sometimes dislocated appearances presented by the latter. The two hypotheses have some points in common; for it is evident that in order to account for the transportation of such enormous masses by means of *ice rafts*, we must suppose that they have been deposited on the surface of the ice-foot by means of *landslips*. Perhaps it will be more logical in all such cases to avoid calling in the agency of these vast ice-floats except in the cases (of which there are many) in which it can be clearly shown not only that the rocks composing the masses are absent in the neighbourhood *now*, but that it is impossible that they could have existed in the vicinity as escarpments during the Glacial period.

The section at Linksfield is now unfortunately closed, the quarrying of the limestone below the shales and Boulder-clay having been abandoned. Admirably detailed descriptions of the succession of the beds, however, have been published by Malcolmson §, Duff ‖, Brickenden ¶, and Moore**.

Although the Linksfield beds are highly fossiliferous, there is considerable difficulty in fixing their exact age. The fallacy of the arguments derived from the mineral characters and the succession of the beds, on the strength of which they have been successively

* These and many examples of transported masses of enormous dimensions will be described in a forthcoming memoir of the Geological Survey.

† Symonds, Edin. New Phil. Journ. New Ser. vol. xii (1860) p. 100.

‡ See Morris, Quart. Journ. Geol. Soc. vol. ix. (1853) p. 317; Ramsay, ibid. xxvii. (1871) p. 252; also Fisher, Geological Magazine, vol. v. (1868) p. 407; and Bonney, ibid. vol. ix. (1872) p. 403.

§ Proc. Geol. Soc. vol. ii. p. 667; and Edin. New Phil. Journ. New Ser. vol. ix. (1859) p. 48.

‖ Sketch of the Geology of Moray, p. 15, plate iii.

¶ Quart. Journ. Geol. Soc. vol. vii. (1851) p. 291.

** Ibid. vol. xvi. (1860) p. 446.

referred to the Wealden, the Purbeck, and the Rhætic, has been already pointed out. The finely laminated variegated clays, the beds of fibrous carbonate of lime ("beef" and "bacon" of the Purbeck quarrymen), the *bone-bed* and numerous scattered fish-remains, the admixture of dwarfed marine with fresh- or brackish-water species, the bands crowded with *Cyprides*, and the abundance of *Estheriæ*, all appear to indicate the prevalence, as in the formations referred to, of *estuarine conditions*; but they afford us no criteria for determining the *age* of the beds. Strata of almost identical mineral characters occur in Sutherland at the base of the Middle Oolites; but I do not find any such community of species between the two sets of strata as would justify their identification. The following is the list of the species which have been obtained from the Linksfield beds.

List of Fossils from the Linksfield Shales.

Femur of a species of Trionyx (determined by Professor Owen).
Vertebræ of Plesiosaurus, sp.
Scales of Semiotus punctatus, *A. Robertson*, M.S.
—— Lepidotus minor, *Ag.*
—— Pholidophorus, sp.
—— Eugnathus, sp.
Teeth of Hybodus Lawsoni, *Duff.*
—— —— dubius, *Ag.*
—— Sphenonchus Martini, *Ag.*
Acrodus, sp.
Spines of Hybodus.
Ostrea, sp.
Pteroperna, sp.
Mytilus, sp.
Modiola Hillana, *Sow.*
——, sp.
Astarte, sp.
Unio, sp.
Cyrena.
Cyclas (several species).
Melanopsis, sp.
Paludina, sp.
Planorbis. sp.
Candona? globosa, *Duff*, sp.
Estheria minuta, *Alberti*, var. Brodieana, *Rupert Jones.*
Spine of Echinoderm.
Neuropteris and other ferns.
Fragments of wood.

Several of the species of marine mollusks which occur at Linksfield appear to be undistinguishable from forms described by Professor Hébert from the Rhætic of Högonäs, in Scania. But the evidently dwarfed and abnormal condition of the fossils in both places is such as to deter me from making any positive identification.

The species of fishes described by Agassiz appear to be nearly all peculiar to this locality; but the general association of the genera, though consistent either with the hypothesis of the Liassic or of the Oolitic age of the beds, seems to be rather in favour of the former. The marine mollusca are all evidently dwarfed, and the determination of their species thus rendered difficult and doubtful; Mr. C. Moore, however, has identified *Modiola Hillana*, Sow., a Lower Lias form. The species of *Cypris* affords us no assistance; but the *Estheria*, though belonging to a species having a very extended range, is referred by Professor Rupert Jones to a variety which has hitherto been obtained only from the Rhætic; yet it is at the same time shown to present some differences from the specimens undoubtedly of that age. It will thus be seen that the palæontological evidence concerning the age of the Linksfield beds is far from being strong or conclusive; but the balance of it is certainly in favour of our considering the strata of Rhætic or Lower-Lias age.

It is possible that, during the "infra-Liassic" period, beds of conglomerate like those of the Dunrobin reefs may have been formed at one point while strata like those of Linksfield were deposited at no great distance. In fact we have a perfectly similar example in the south-west of England in the "Lias-conglomerate" of South Wales and the Rhætic Shales of the Bristol Channel. On the other hand it is very probable that associated with the beds of Lower-Lias age which contain coal-beds and are so imperfectly exposed at Dunrobin, the exact counterpart of the Linksfield shales may exist. At the same time, the presence of beds in this district formed under similar estuarine conditions at various horizons during the Jurassic period will justify us in hesitating to fix absolutely the age of the isolated strata of Linksfield, in the absence of more precise palæontological evidence.

A number of fragmentary masses of strata similar to that of Linksfield have been found at several places in the neighbourhood—namely, at Maryhill, Pitgaveny, Spynie Hill, and Waukmill.

The close resemblance between the fossils of the strata at Linksfield and those so admirably described by M. Hébert in very similar beds at Högonäs, in Sweden, if it does not warrant the absolute identification of the two series, affords strong grounds for the suspicion that they are on nearly the same geological horizon.

§ 3. *The Lower Lias.*

The conglomerates and sandstones on the shore at Dunrobin, which we have shown reasons for regarding as of Rhætic age, are covered conformably by, and, indeed, appear to graduate into, an interesting series of estuarine strata, composed of sandstones, shales, and beds of coal, and attaining a very considerable thickness, which I estimate from the angle of dip and breadth of outcrop to be not less than from 400 to 500 feet (see fig. 14, *d*, page 143). Unfortunately these strata are very imperfectly exposed; for under ordinary circumstances only the harder beds appear as reefs upon the shore; when, however, the beach is temporarily scoured away by heavy storms, the bassets of the softer strata of clay and coal are sometimes exposed. It was thus that a bed of coal was exposed to the E.N.E. of Dunrobin Pier, which led in the year 1770 to a boring being undertaken in the Summer-house Park adjoining. The only record of this boring which remains states that "two thin seams of coal were proved, but not deemed worth working."

The sandstones of this series appear to present the usual characteristics of the arenaceous type of the Jurassic estuarine beds. They sometimes contain numerous laminæ of carbonaceous matter, and at others are crowded with vertical plant-markings, like the so-called "root-beds" of the Midland district of England. In one of the highest of these beds of sandstone I detected casts of *Pecten* and other marine shells, indicating that there is a gradual passage from these estuarine strata to the marine beds overlying them. The carbonaceous seams associated with the series appear to be well-

formed coals, and not lignites, but they contain much pyrites. The argillaceous strata I have never found sufficiently well exposed to enable me to make an adequate examination of them.

Lithology.	Thickness.	Fossils.
(*Clays of the Middle Lias.*)		
(1.) Bed of coarse blue sandstone, in places highly micaceous, with a few pebbles of quartz scattered through it. The top of this bed is highly pyritous; and the bottom passes into a grit.	1 ft. 6 in.	Fossils rare:— *Belemnites acutus*, Mill. *Pecten sublævis*, Phil. *Pecten liasinus*, Nyst.
(2.) Beds of very sandy micaceous blue clay, with a few irregular and inconstant bands of sandstone.	3 ft.	*Gryphæa obliqua*, Sow. (dwarfed form), very abundant. *Pleuromya*, *Pecten*. Casts of other bivalves.
(3.) Alternations of very hard laminated fine-grained micaceous sandstone and shaly micaceous sandy blue-clay.	3 ft.	Few fossils.
(4.) Thick mass of finely laminated sandy and highly micaceous blue-clay, the joints of which are filled with sandstone.	8 ft.	A few scattered Oysters. *Pleuromya unioides*, Röm., sp. Carbonaceous markings.
(5.) Soft, somewhat micaceous, laminated sandstone of a greenish colour (graduating downwards into 6).	3 ft.	A few carbonaceous markings.
(6.) Thick bed of blue micaceous clay, with irregular bands of sandstone. In its lower part this bed becomes less sandy, and contains some septaria.	About 15 ft.	Carbonaceous markings abundant. A few fossils scattered through it:—*Rhynchonella variabilis*, Schloth., var.; *Lima pectinoides*, Sow.; *Gryphæa obliqua*, Sow. (dwarfed form); *Cardinia hybrida*, rare; *Pleuromya unioides*, Röm., sp., rare; *Belemnites acutus*, Mill.; crushed bivalves.
(7.) Alternations of clays and limestones crowded with Oysters and *Cardiniæ*, and other shells. There are two principal beds of limestone; and these occasionally contain quartz pebbles scattered through them.	16 ft.	Fossils very abundant:—*Ammonites* and *Belemnites*; *Gryphæa obliqua*, Sow.; *Cardinia hybrida*, Sow., sp.; *Lima pectinoides*, Sow., sp., &c. &c. (see list).
(8.) Bed of greenish very micaceous sandstone.	2 ft.	Few fossils. Cast of *Pecten*. Full of Fucoid (?) markings.
(9.) Finely laminated, highly micaceous, dark blue-clays.	10 ft.	Crushed shells (*Cardinia* and *Pecten*). Wood.
(10.) Soft greyish blue sandstone.	9 in.	Oysters and other shells (fragmentary).
(11.) Blue clay.	Bottom not seen, about 20 ft.	*Cardinia hybrida*, Sow., sp. *Gryphæa obliqua*, Sow. (dwarfed form). Crushed bivalves.
(*Estuarine sandstones, coals, &c.*)		

At the top of this series of estuarine strata we find a formation, consisting of alternations of blue micaceous clays and hard impure

shelly limestones, and containing very numerous marine fossils (see fig. 14, *e*, page 143). Although these strata are unquestionably marine, yet the nature of the beds, the assemblage of genera in their fauna, the dwarfed condition of the Oysters and some other forms, and the abundance of fragments of carbonaceous matter lead us to regard them as formed under comparatively shallow-water conditions; and, as we have already seen, they graduate into the estuarine strata below. These beds are tolerably well exposed in a number of reefs on the shore, a little to the north-east of Dunrobin Castle, which reefs have a nearly E. and W. strike, and a northerly dip of from 12° to 15°. The nature, order of succession, and palæontological features of these strata are shown in the Table (p. 150), the thicknesses being partly measured, and partly estimated.

The species of fossils derived from these beds, which I have been able to accurately determine, are as follows, the majority being obtained from the division marked (7):—

Fossils of the Lower Lias Limestones and Shales. Dunrobin Reefs.

Belemnites acutus, *Mill.* (abundant, but small).
Ammonites caprotinus, *D'Orb.* (abundant, but badly preserved).
——, sp. (rare).
—— oxynotus, *Quenst.* (tolerably abundant).
—— ——, var. (rare).
Panopæa, sp.
Pholadomya ambigua, *Sow.*, var.
——, sp.
Pleuromya unioides, *Röm.*, sp.
Tancredia ?, sp.
Hippopodium, sp.
Cardinia lanceolata, *Stutch.*, sp. (not rare).
—— ——, var.
—— hybrida, *Sow.*, sp. (very abundant).
Unicardium cardioides, *Phil.*, sp.
Modiola, spec. nov.
Mytilus (Modiola) numismalis, *Oppel.*
Pecten, sp.
—— liasinus, *Nyst.*
—— tumidus, *Ziet.*
—— textorius, *Schloth.*
—— sublævis, *Phil.*
Pinna Hartmanni, *Ziet.*
Lima Koninckana ?, *Chap. et Dew.* (rare).
—— punctata, *Sow.* (rare).
—— pectinoides, *Sow.*, sp. (very abundant).
Ostrea ?, sp.
Gryphæa obliqua, *Sow.* (rare).
—— ——, *Sow.* Dwarfed variety of Quenstedt (very abundant).
Rhynchonella tetrahedra, *Sow.* (abundant).
—— variabilis, *Schloth.*, var. triplicata, *Phil.*
Wood, &c.

The series of estuarine and associated marine strata which we have been describing was noticed by Sir Roderick Murchison in his earliest memoir. Unfortunately the fossils then collected by him were few in number, and the determination made of them not of a

sufficiently exact character for fixing the age of the beds; but from the resemblance in petrological characters of the strata exposed at Dunrobin to those near Brora, he was led to regard the former as a mere repetition of the latter, and therefore of Lower-Oolite age. In later years Sir Roderick Murchison obtained specimens of *Hippopodium ponderosum*, Sow., from the Dunrobin shore, and was thus led to the recognition of the fact that strata of Liassic age exist there*.

The two patches of strata which were in 1826 referred to the Lias by the same author as the result of a confessedly somewhat hasty examination†, and which have since been almost uniformly so regarded by geologists in Scotland, will be shown in this memoir to be of the age of the Coralline Oolite and the Kimmeridge Clay respectively.

With regard to the marine strata, which form the upper part of the series we have been describing as occurring at Dunrobin, there is fortunately no room for doubt as to the question of their position in the geological scale. An inspection of the list of fossils will show that the beds which yield them undoubtedly belong to the Lower Lias, and to that part of it which Quenstedt has distinguished as the Lias β. This is the highest portion of the Lower Lias according to the classification usually adopted on the Continent, but its middle portion according to the English method of grouping the beds.

The fauna of these beds at Dunrobin is not without some anomalous characters, some of which, such as the rarity and small size of the Cephalopoda, the dwarfed condition of the Oysters, and the absence of Echinoderms and of many of the species of Mollusca usually found at this horizon, may be accounted for on the ground that the beds were probably deposited under less favourable conditions than their typical equivalents in England and Swabia. These unfavourable conditions would appear to have been the shallower and less tranquil state of the sea, and possibly also the colder climate. Certain other of the peculiarities, as for example the association in the same bed of species which in Swabia characterize distinct but contiguous horizons, must be referred to the fact that the beds were deposited in a remote locality, and that the character of the fauna would thus be influenced by the varying migrations of some, and the unequal persistence and gradual extinction of other species. Nevertheless, in spite of these minor peculiarities, no one acquainted with the association of Jurassic species in England, Northern France, and Western Germany, can hesitate to regard these beds in the north of Scotland as the deposits of a portion of the same great sea, and as included within the same ancient province of marine life.

Having thus, by means of the beautiful marine fauna of its higher beds, fixed the newer limit of age of the series of estuarine beds at Dunrobin, the base of which is formed by deposits certainly Triassic, and others probably Rhætic, we can have little hesitation in regard-

* See First Sketch of a Geological Map of Scotland, 1861; also Quart. Journ. Geol. Soc. vol. xv. (1859) plate xii.

† Trans. Geol. Soc. 2nd ser. vol. ii. part 2, p. 307.

ing these same estuarine strata as representing the lower part of the Lias β and the whole of the Lias α of Quenstedt. That marine representatives of these strata were wanting on the east coast of Scotland appears to be proved by the following fact. It will be shown that of almost every portion of the series of Jurassic strata seen in Sutherland, fragments, often very numerous and sometimes of enormous size, are found in the drifts of the east coast of Scotland; but among the numerous series of fossils collected from these same drifts I have never yet detected a single example of the usually remarkably abundant *Gryphæa arcuata*, Lam. (*G. incurva*, Sow.), nor of any of its associated forms. Marine strata of this age, however, are, as will be shown hereafter, remarkably well developed on the western coasts of Scotland.

Of the marine strata forming the upper part of the Lower Lias very numerous fragments occur in the drifts of the east of Scotland. Mr. A. Robertson collected at Inverugie a large series of fossils from fragments of shelly limestone of this age; and I found at Kaim, to the north-west of Elgin, numerous large boulders derived from the same source. These transported fragments appear to indicate that in the east of Scotland there once existed beds of limestone of this age, thicker and better-defined than those in the patch which has escaped destruction at Dunrobin. The following fossils have been collected at Kaim and Inverugie:—

Fossils from transported blocks of Lower Lias (micaceous sandy limestone) at Kaim, Elginshire.

Ammonites caprotinus, *D'Orb.*
Cardinia hybrida, *Sow.*, sp.
—— crassiuscula, *Sow.*, sp.
——, sp.
Hippopodium, sp.?
Cypricardia, sp.
Unicardium cardioides, *Phil.*, sp.
Pecten textorius, *Schloth.*
—— tumidus, *Ziet.*
—— liasinus, *Nyst.*
Ostrea semiplicata, *Münst.*
Gryphæa obliqua, *Sow.*, var.
Rhynchonella variabilis, *Schloth.*

Fossils from boulders of Lower Lias (same rock as last) at Inverugie, Elginshire.

Ammonites oxynotus, *Quenst.*
—— caprotinus, *D'Orb.*
—— Masseanus?, *D'Orb.*
Pleurotomaria, sp.
Natica, sp.
Panopæa, sp.
Pleuromya unioides, *Röm.*, sp.
Anatina?, sp.
Pholadomya ambigua, *Sow.*, var.
Ceromya?, sp.
Cardinia hybrida, *Sow.*, sp.
—— crassiuscula, *Sow.*, sp.
——, sp.
Hippopodium, sp.
Unicardium cardioides, *Phil.*, sp.
Cypricardia, sp.
Astarte, sp.
Myoconcha psilonoti?, *Quenst.*
Modiola scalprum, *Sow.*
—— Hillana, *Sow.*
Mytilus, sp.
Lima pectinoides, *Sow.*, sp.
—— punctata, *Sow.*, sp.
Pinna Hartmanni, *Ziet.*
Avicula sinemuriensis, *D'Orb.*
—— (Monotis) papyrea, *Quenst.*
Pteroperna (Gervillia) betacalcis, *Quenst.*
Plicatula spinosa, *Sow.*
Pecten textorius, *Schloth.*
—— liasinus, *Nyst.*
—— tumidus, *Ziet.*
——, sp.
Gryphæa obliqua, *Sow.*, var.
Ostrea semiplicata, *Münst.*

In Scania, in the neighbourhood of Helsingborg, &c., the strata of Rhætic age, which we have referred to as existing at Högonäs are covered by a great series of beds of sandstone, micaceous shales, impure lignites, and coals. These are said to attain, in places, a thickness of 1000 feet. In the Prince-Charles Mines a pit has been sunk to the depth of 280 feet, which passed through five beds of coal, the first four being only from 4 to 6 inches thick; but the lowest, which, however, contains some intercalated seams of clay, is upwards of 4 feet thick. The sandstones of Hör, too, which have yielded a very interesting flora, are shown also to belong to the base of the Lower Lias. This agreement in characters between the strata of the same age in Scotland and Scandinavia, of which only such isolated fragments now remain, is a point of great interest and suggestiveness.

§ 4. *The Middle Lias.*

Reposing on the fossiliferous clays and limestones at Dunrobin, which we have just described, we find a considerable thickness of dark blue, very finely laminated and highly micaceous clays, containing a few thread-like concretions of pyrites, and very numerous, small, and curiously shaped nodules of argillaceous limestone (see fig. 14, *f*, page 143). At some distance from the base very large septaria occur, and still higher a few irregular indurated bands containing Oysters and *Hippopodium ponderosum*, Sow.

The total thickness of clays seen here is about 80 feet, as estimated from the dip and breadth of outcrop. To the north the shore is altogether covered by great boulders. There is good reason, however, for believing that a great transverse fault occurs near here, which brings the clays of the Middle Oolite, which are seen in the brickyard and trial-pits at Clayside, against the clays of the Middle Lias. The clay-beds, on the shore at Dunrobin, have yielded a considerable number of fossils, sufficient, indeed, to place their age beyond question; these are recorded in the following list:—

Fossils of the Middle-Lias Clays, Dunrobin Reefs.

Belemnites acutus, *Mill.* (abundant, but generally very small).
—— clavatus, *Schloth.*
Ammonites brevispina, *Sow.* (not rare).
—— ——, var.
—— Jamesoni, *Sow.*, var. (rare).
—— oxynotus, *Quenst.*, var. (very rare).
Helicina expansa ?, *Sow.*, sp.
Turbo canalis, *Goldf.*
Pholadomya decorata, *Goldf.*
Pleuromya unioides, *Röm.*, sp.
Cardinia lanceolata, *Stutch.*, sp.
—— attenuata, *Sow.* (rare).
Hippopodium ponderosum, *Sow.*, large rugose variety (very abundant).
Cardium truncatum ?, *Sow.*
Unicardium cardioides, *Phil.*, sp.
Cucullæa Münsteri, *Goldf.*
Arca Buckmanni, *Rich.*
Mytilus (Modiola) numismalis, *Oppel.*
Limea acuticosta, *Goldf.*
Lima pectinoides, *Sow.*, sp. (rare).
——, sp.
Pinna folium, *Y. & B.*
Pecten liasinus, *Nyst.*
—— sublævis, *Phil.*
—— priscus, *Schloth.*
Plicatula spinosa, *Sow.*
—— lævigata ?, *D'Orb.*
Gryphæa cymbium, *Lam.* (G. Maccullochii, *Sow.*).
—— obliqua, *Sow.*, var.
Terebratula punctata, *Sow.*
Rhynchonella amalthei, *Quenst.*
Pentacrinus moniliferus, *Quenst.* (rare).
Wood in form of jet.

The geological horizon indicated by this fauna is not less clear than that of the beds below. The age of the thick beds of blue clay at Dunrobin is, without doubt, that of Quenstedt's Lias γ (that is, the lower part of the Middle Lias of continental geologists, the higher part of the Lower Lias according to our English classification). These beds were probably deposited in deeper and more tranquil water than were those below them, the conditions indicated being not very dissimilar to those which must have prevailed during the deposition of the equivalent strata in England. The peculiarities of their fauna, therefore, such as the persistence of *Ammonites oxynotus*, Quenst. (though in a dwarfed condition), and of *Belemnites acutus*, Mill., both of which species become extinct in the typical localities before the close of the Lias β period, as well as the rarity of the Ammonites, especially those of the group of the *Armati*, usually very characteristic of the zone, can only be ascribed to difference of climate or to their geographical position, so remote from the sections which have served as standards of our Liassic classification.

Although no higher beds in the Middle Lias series are exhibited in Sutherland, owing to the fault referred to, we are fortunately not left altogether in doubt as to the characters assumed by the strata of that age in the east of Scotland. Among the boulders in Elginshire and the adjoining counties, none are more common than masses composed of a fine-grained micaceous sandstone, of a light colour, crowded with fossils which prove them to belong to the horizon immediately above that of the clay just described. Among the localities which have yielded such boulders I may mention especially the Loch of Spynie, Lhanbryd, Ashgrove near Elgin, Urquhart, several spots near Banff, &c.

When I have described the Middle Lias strata of the western coast of Scotland, their similarity to those just described in the micaceous sandstones above and the blue shales below, will be made apparent. It will be seen that during the periods represented by portions of the Middle Lias and the Middle Oolite, more uniform and comparatively deep-water marine conditions prevailed in Scotland. The full consideration of this and similar questions, however, I reserve for the third part of this memoir.

At two localities, namely Lhanbryd and Loch Spynie, the fragments of the Middle Lias sandstone have been found in such abundance as to lead to the impression that the rock is *in situ* at or near the place. A careful examination of the question, however, shows that the masses of rock are certainly enclosed in the Boulder-clay. The accumulation of portions of the same bed at certain points may be accounted for, as already hinted, by regarding them as brought by an iceberg which had received its freight of detritus at some locality where the parent rock was developed. The species of fossils from these two localities are so numerous, interesting, and well preserved, that I am induced to give lists of them. Those from Loch Spynie are nearly all from the cabinet of that indefatigable collector, Mr. Grant, of Lossiemouth.

List of Fossils from boulders of Middle Lias (micaceous calcareous sandstone), Loch Spynie, Morayshire.

Glyphea rostrata, *Phil.*, sp.
Belemnites paxillosus, *Schloth.*
Ammonites Jamesoni ? *Sow.*, var.
Helicina expansa, *Sow.*, sp.
Chemnitzia undulata, *D'Orb.*, sp.
Turritella, sp.
Turbo, sp.
Trochus, sp.
Pleurotomaria, sp.
Cylindrites, sp.
Pholadomya ambigua, *Sow.*, var.
Myacites, sp.
Pleuromya unioides, *Röm.*, sp.
Panopæa elongata, *Röm.*
Isocardia ?
Goniomya, sp.
Arca Buckmanni, *Rich.*
Myoconcha scabra, *Terq.* et *Piette.*
Cypricardia, sp.
Unicardium cardioides, *Phil.*, sp.
Cardium truncatum, *Sow.*
Cardinia, sp. (rare).
Modiola scalprum, *Sow.*
Lima, sp.
Pinna folium, *Y. & B.*
Pecten liasinus, *Nyst.*
—— sublævis, *Phil.*
—— disparilis, *Quenst.*
Plicatula spinosa, *Sow.*
—— lævigata ?, *D'Orb.*
Placunopsis, sp.
Gryphæa obliqua, *Sow.*
Serpula, sp.

List of Fossils from the boulders of Middle-Lias rocks found at Lhanbryd, Elginshire.

Belemnites paxillosus, *Schloth.*
Ammonites Actæon, *D'Orb.*
—— oxynotus ?, *Quenst.*
——, sp.
Helicina expansa, *Sow.*, sp.
Pleuromya unioides, *Röm.*
Myacites, sp.
Panopæa elongata, *Röm.*
Cardinia philea, *D'Orb.*
Hippopodium, sp.
Unicardium cardioides, *Phil.*, sp.
Cardium truncatum, *Sow.*
Isocardia ? sp.
Tancredia, sp.
Cucullæa, sp.
Lima pectinoides, *Sow.*
—— punctata, *Sow.*
Avicula inæquivalvis, *Sow.*
Crenatula ventricosa, *Sow.*
Pinna folium, *Y. & B.*
Hinnites (near abjectus, *Phil.*).
Pecten disparilis, *Quenst.*
—— sublævis, *Phil.*
—— liasinus, *Nyst.*
Gryphæa obliqua, *Sow.* (dwarfed form).
Ophioderma Egertoni, *Brodie.*
Dicotyledonous wood.

Although, as already noticed, these fossils are certainly derived from transported masses (the only rock of Jurassic age certainly *in situ* on the south side of the Moray Firth being that already described as occurring at Stotfield), yet it must be remembered that over very large areas the rocks are totally concealed by drifts; and, as we have seen that they are traversed by a number of faults of great magnitude, it is possible that these fragments with Jurassic fossils, so abundant in the Elginshire drifts, are not far distant from their parent rocks, which may, indeed, in places, underlie the vast masses of Boulder-clay which mask the country.

§ 5. *The Upper Lias.*

At this horizon we have an unfortunate gap, the only complete one, in the series of beautiful sections of the Jurassic strata in Sutherland. It is quite possible that the very thick series of estuarine strata (sandstones, shales, and coals) which underlies the Middle Oolites of this district, may represent both the Lower Oolites and the Upper Lias also. That the latter era in the east of Scot-

land was either marked by the deposition of estuarine strata, or is totally unrepresented, is rendered highly probable by the fact that, among the numerous Jurassic fossils derived from the drift, I have never been able to find a single example of the very characteristic and well-marked Upper Lias forms.

§ 6. *The Lower Oolite.*

In Sutherland the place of the Lower Oolites is occupied by a thick mass of sandstones, shales, and coals, exhibiting many evidences of deposition under estuarine conditions. This series of strata is directly and conformably overlain by a great thickness of marine strata, representing the lower portions of the Middle Oolite. The great series of estuarine beds is thus proved to be older than the Middle Oolite by the fact that the lowest of the marine strata is, as we shall show hereafter, a bed representing the Kelloway Rock, and containing a fauna which enables us to refer it without doubt to the *lowest* zone of the Middle Oolite. That the estuarine beds, in part at least, represent the Lower Oolites, is confirmed by the fossils found in one of the marine beds included in the series. We have already pointed out that there are reasons for supposing that this estuarine series, which is certainly of great thickness, and of which the base has never been reached, may represent the Upper Lias as well as the Lower Oolite. There is, unfortunately, no point at which the relations of this set of beds with the known Liassic strata of the district can be observed.

These estuarine strata, as might be anticipated from their mode of origin, are very inconstant in character, so that sections at short distances from one another often exhibit surprising differences in the order and thickness of the strata passed through. The highest beds of the series were very carefully studied by Mr. Alexander Robertson, who laid accounts of his observations before this Society in 1843 * and 1846 †.

The following is a generalized section of this series of beds so far as it is known at Brora :—

	ft.	in.
"Roof-bed" of the coal. Base of the Middle Oolite (marine).		
(1) Main bed of coal. Sometimes a well-formed coal of good quality, at others approaching more in character to a lignite. In places it is seen to be wholly made up of the crushed stems of *Equisetites columnaris*, Brongn. This bed of coal contains in its midst a band of pyrites about 6 inches thick, which greatly detracts from the value of the seam. Maximum thickness	3	6
(2) Beds of black highly carbonaceous shale, often crowded with plant-remains, and alternating with thin bands of crushed shells (*Unio*, *Cyrena*, *Perna*, *Ostrea*, &c., and *Cyprides*). In some of the beds the scales and teeth of fishes abound (*Lepidotus*, *Semiotus*, *Pholidophorus*, *Hybodus*, *Acrodus*, &c.); and these occasionally form thin bone-beds. This series of beds includes in its upper part several beds of coal, varying in thickness from 16 inches downwards; but these do not appear to be so constant as the main		

* Proc. Geol. Soc. vol. iv. p. 173.

† Quart. Journ. Geol. Soc. vol. iii. (1847), p. 113.

	ft.	in.
seam. (These beds, from their resemblance in mineral character to some of the Wealden strata, have been identified with that formation)	26	0
(3) Beds of brown, greenish-grey, drab, and black, somewhat sandy clays (fire-clays), with seams of light-coloured argillaceous limestone, sometimes in nodules and at other times forming continuous bands. These beds contain some thin seams of imperfect coal, much mingled with pyrites. Fossils are rare in them; but occasional *Cyrenæ* or dwarfed *Ostreæ* occur, indicating their estuarine character	96	0
(4) Coarse white sandstones	39	0
(5) Clays like 3	7	0
(6) White sandstone	25	0
(7) Alternations of sandstone and clay	37	6
(8) White sandstone (thickness unknown).		

This series of estuarine strata has been proved to the depth of about 230 feet; but its thickness is probably much greater.

The coal-bed (1) is seen on the shore at Brora, near the old salt-pans; and at this place it has frequently been dug, the overlying "roof-bed" having been often removed by blasting; it now forms a very conspicuous reef on the shore at low water. Along the shore opposite and to the northward of this outcrop, a number of shallow pits have been sunk in the Inverbrora * Links at various dates since 1598 for working this bed and those a short distance below. The sites of many of these old pits can still be traced. In the valley of the river Brora, and at a distance of rather more than half a mile from its mouth, pits have been sunk to this coal-seam, which is there about 230 feet from the surface. The same bed of coal is repeated by a fault to the southward, and is seen in the cliff at Strathsteven, and possibly also at Clayside.

The series (2) is that described by Mr. Robertson as so remarkably illustrating the fresh-water origin of some of the beds. I saw it well exposed in a trial-hole at Strathsteven cliff. It can only be examined in artificial sections. The carbonaceous shales below the main coal-seam are very inflammable; they have been tested, in order to discover if they will yield illuminating oils like that obtained from the celebrated Torbane-hill mineral. The result of these trials, however, was not encouraging.

The beds of (3) have been exposed in several borings in search of coal; and they can also be fairly well traced on the shore, where the harder bands form reefs. During my residence at Brora I had an excellent opportunity of studying the nature and succession of the beds in a shaft and boring which were carried to a depth of 75 feet, in a futile endeavour to find coal.

The strata (4 to 8) can be traced on the shore, and were also penetrated by a boring in 1770. The sandstones (8) are evidently of great thickness. As we trace the strata to the southward along

* It may be well to mention that the name of Inverbrora was originally given to the fishing-village at the mouth of the river Brora. At the present time the name is applied to a farm at some distance inland.

the shore, we find their strike to change gradually from N. by E. and S. by W. to E.N.E. and W.S.W.; it is difficult to determine whether the thick masses of sandstone which are seen in the cliffs at Strathsteven, and which are worn into caves at Sputie Bay, regularly underlie the beds already enumerated; but it is probable that such is the case. On the shore at Strathsteven beds of clay and argillaceous limestone, containing a bed of coal about 18 inches thick, are seen. Near this point, the sandstones, which are usually very destitute of any trace of fossils, contain a few casts of marine shells in one of the beds. These are, unfortunately, very badly preserved as casts only, and rarely capable of specific determination.

Quenstedtia oblita (?), *Phil.*, sp.
Lucina, sp.
Trigonia, sp. (cast).
Astarte elegans (?), *Sow.*
Myacites decurtatus, *Phil.*, sp.
Pecten (ribbed species).
—— articulatus, *Schloth.*
—— demissus (?), *Phil.*
Large masses of wood (casts).

Obscure as these fossils are for the most part, there can be little doubt that the beds which yield them belong to the Lower Oolite.

The thick masses of sandstone which are seen in the Strathsteven cliffs exhibit much false-bedding, and often many seams of carbonaceous matter; they yield a good and easily worked freestone, hardening rapidly on exposure, which was once extensively dug at the Cleat quarries. The opening of the quarries in the Triassic sandstones on the south side of the Moray Firth, at Covesea, Hopeman, &c., has caused the almost total abandonment of the Sutherland quarries, a result due not so much to the superiority of the rock at the former localities as to the greater facilities there both for its shipment and land transport.

The sandstones about Strathsteven present the usual characters of the arenaceous type of estuarine series. The stratification is often obscure; the beds appear to dip S.E. 20° near the Cleat quarry. Sometimes the rock is ferruginous, and when exposed in reefs on the shore assumes a bright red colour. Two borings, of nearly 200 feet, have been put down in these beds at Strathsteven. One of these, made by Mr. William Miller in 1798, by the side of the parliamentary road, gave the following section:—

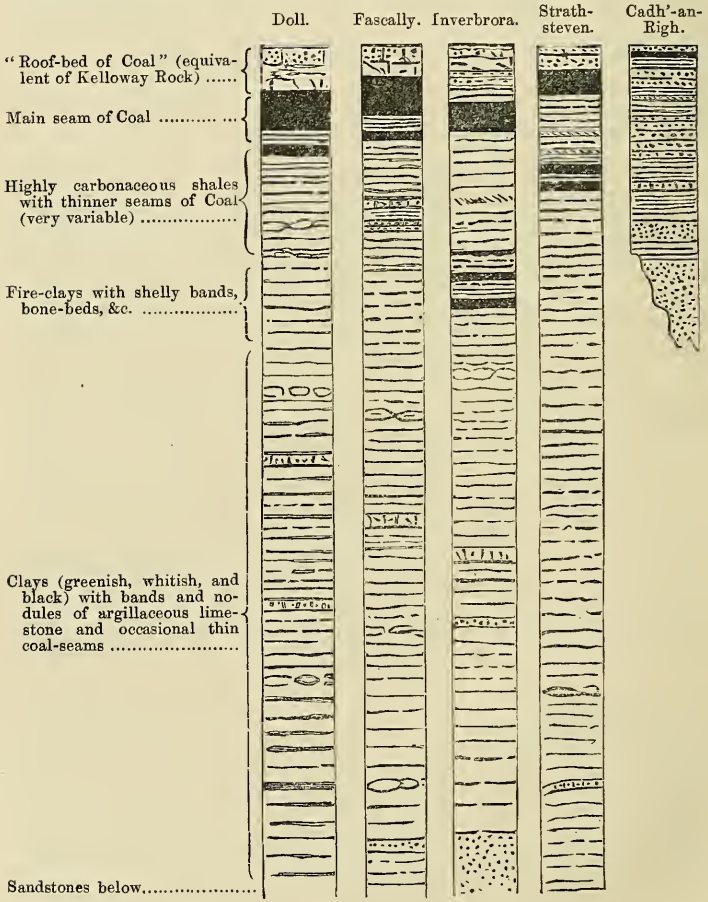
	ft.	in.
"Various metals"	31	0
Soft rotten freestone	18	2
Hard white freestone	109	6
Limestone	4	6
"Whinstone" (Cherty grit?)	1	4
"Blae or Till" (Blue clay)	5	1
"Whinstone"	0	8
Soft or rotten freestone	4	1
"Whinstone" (not cut through)	2	5
Total	176	9

As already observed, the base of this series of strata has nowhere been reached by boring; and on account of the great transverse faults, which let down a patch of newer strata between Strathsteven

and Dunrobin, the relations of the great series of estuarine beds to the Liassic rocks cannot be seen.

In order to illustrate the variations in the thickness and order of succession of these estuarine strata, I subjoin a number of sections obtained by shafts and borings at various points, beginning in every case with the "Roof-bed"—that is, the lowest bed (marine) of the Middle Oolite (see fig. 15).

Fig. 15.—*Comparative vertical Sections of the Coal-bearing Strata of Lower Oolite age in Sutherland and Ross.* (Scale 20 ft. to 1 in.)



(1) Boring on shore at Inverbrora by John Pritchard, 1811:—

	ft.	in.
"Roof bed"	4	0
Blue bind	3	6

	ft.	in.
Main seam. { Coal, sooty, 2 inches; Coal (very good, except 2 or 3 inches in the middle) 2ft. 4in.; Coal 4 inches }	2	10
Black bass	7	0
Blue bind	19	0
Coal	0	10
"A soft pricking coal" (carbonaccous shale?)	0	10
Coal	0	11
Blue bind (not cut through)	27	1

(2) Boring in Inverbrora Links by John Evans, 1770. (N.B. Commenced below the roof-bed and main seam of coal.):—

	ft.	in.
Soft blue "mettal" (or bind)	12	8
Coal, soft	0	4
Soft blue "mettal"	2	0
Coal, soft	1	2
Soft grey "mettal" (or bind)	60	0
White post or sandstone	1	6
Soft grey "mettal" with girdles (or balls)	5	0
Soft black "mettal"	1	6
Soft blue "mettal"	3	0
Soft "mettal"	0	6
Black "mettal" and coals	0	2
Grey "mettal stone" (or clunch)	6	0
Strong "mettal stone"	3	0
Soft grey "mettal" with girdles	15	6
White post or Freestone	39	0
Soft grey "mettal" (bind or clay)	7	0
White post with hard lumps	25	0
Grey "mettal stone" with post girdles	27	6
White post or sandstone	2	6

(3) Boring in Inverbrora Links to the northward of the last, by John Evans, 1770:—

	ft.	in.
Blue sandy bind with shells; Grey post (or sandstone) 9 inches; Whinstone (or coarse limestone, 2 ft.... } "Roof-bed."		
Grey post (or bind)	5	6
Coal (with a little mixture of black stone, 2 ft. 6 in.); Coal, Parrot, 3 in. }	2	9
Black stone (or coaly bass)	7	0
Grey stone (or bind) not cut through	6	0

(4) Boring for coal at Water of Brora (Fascally), 1811:—

	ft.	in.
"Roof-bed"	4	4
Hard caking coal (main seam)	3	2
Black clunch	2	0
Hard splent coal	1	4
Black burning shale, like Cannel coal	6	7
Very hard stone	1	2
Black shale	2	0
Very hard stone	0	2½
Soft black shale speckled with white powdery matter (shelly band)	0	2
Hard black burning shale	4	2

(5) Boring for coal, Engine Pit, south of the river Brora, by William Hughes, 1814:—

	ft.	in.
"Roof-bed"	5	0
Main coal	3	8
Bituminous shale	2	0
Slate coal with pyrites, not workable	1	4
Fine clay alternating with shale	90	0

(6) Section exposed in the coal-workings at Strathsteven Cliffs, where the strata are faulted against the Strathsteven sandstone; observed 1872:—

	ft.	in.
"Roof-bed," hard greenish sandstone weathering brown, full of shells, *Myacites recurvus*, Phil., *Astarte minima*? Phil., *Gresslya peregrina*, Phil., &c. Many small pebbles of the size of peas	3	0
Greenish sandy clay.	seen	
Bed of coal (main seam) with a band of pyrites in its midst	2	6
Dark-coloured bituminous clay, with many compressed Equisetites, and several thin seams of white sand	5 to 6 ft.	
Seam of white shells—*Perna* very abundant, also *Cyrena*, &c., and *Cypris*	0	3
Black clay, with many flattened specimens of *Equisetites* coated with pyrites, many plant-remains and coaly seams, scales of *Lepidotus*	1	2
White seam crowded with shells of *Perna*, *Ostrea*, *Cyrena*, *Cypris*, &c., very variable in thickness	1 in. to 5 in.	
Black clay, with a band of shells (*Unio*?) at the bottom	1	3
Coal seam (*made up of stems of Equisetites*)	10 in. to 12 in.	
Black clay Thin white shelly seam	1	0
Coal seam	1	0
Black clay with nodules of pyrites and many plant-remains.		

These strata are very irregular; the coals vary in thickness in the course of a few yards; and the shelly bands become split up and unite again in places. The strata are greatly disturbed, being near a fault (which was proved by these workings), and dip N. 37°.

(7) Boring at Clayside, probably in the same set of beds, the "roof-bed" not being seen, however; 1872:—

	ft.	in.
Coal of fair quality (thickness not ascertained) immediately underlying drift.		
Stiff dark-coloured clay	20	6
White sandy stone	1	6
Sandy light-coloured fine clay	3	6
White sandy rock	2	0

(8) The last section which I shall notice is that of Cadh'-an-Righ, on the Ross-shire coast, at a distance of 19 miles from Brora; this is interesting, as showing the differences which have taken place in the strata, and the way the coal has almost thinned out. (See fig. 8, p. 125.)

	ft.	in.
"Roof-bed" with fossils	1	0
Coal (main seam), a poor carbonaceous band	4 or 5 in.	
Carbonaceous clay	2	0
White sandstone with plants	2	0

	ft.	in.
Dark grey clay with *Cyrena*	1	0
Hard white band, made up of shells, *Cyrena*, *Perna*, &c. (same species as at Brora)	0	9
Dark grey clay	2	6
Band of argillaceous limestone	0	6
Greenish grey sandy clay passing into green sandstone	3	0
Light-coloured argillaceous limestone	1	0
Light-grey indurated fire-clay	2	0
Argillaceous limestone	0	9
White sandstone about	20	0
Light-blue sandy clay (faulted against the Lower Old Red Sandstone and Conglomerate).		

The question of the economic value of the coal-seams of Sutherland need not be entered upon in this memoir. The former history of the mining operations in the district, a history, unfortunately, like that of the workings in the similar rocks of the north-east of Yorkshire, of almost continual disappointment and loss, has been already sketched, by both Sir Roderick Murchison * and Hugh Miller †. The possibility of the profitable working of these thin coal-seams, under the existing somewhat adverse conditions, is a question belonging solely to the mining engineer. I may state, however, that the present noble proprietor of the estates has determined that a trial of the capabilities of the district, under the most advantageous conditions possible, shall be made, so as finally to settle a question of so much importance in connexion with his extensive property in the Highlands. The old Brora mines are now being pumped out, and will in a short time be again in working. The reports which have been circulated of the discovery of new deposits of coal in the district are altogether destitute of foundation.

The last point at which we have to notice the existence of Lower Oolite strata in the east of Scotland is at Stotfield, in Elginshire. This highly interesting patch of fossiliferous rocks was brought under my notice by Dr. Gordon, of Birnie, to whom it has long been known. There is no reason whatever for doubting that the strata yielding the fossils here are *in situ*; and, as already pointed out (page 128, fig. 12), they appear to be faulted against the "Cherty rock of Stotfield" and the Reptiliferous Sandstone.

The rocks here appear to consist of soft greenish white sandstones, graduating into very hard quartzite-like rock, sometimes containing carbonaceous markings. These rocks frequently weather on the shore to a bright red colour. Only one bed, which can be traced for some distance along the shore, yields fossils; and these are almost all in the condition of casts. In all respects these Lower Oolite rocks in Elginshire agree very closely with their equivalents in Sutherland, which I have already described.

I am indebted to Mr. Grant, of Lossiemouth, who has spared no pains in making as complete a series as possible of the rather obscure but very highly interesting fossils of this rock at Stotfield,

* Trans. Geol. Soc. 2nd ser. vol. ii. pt. 2 (1826), p. 324.
† Sketch-book of Popular Geology (1859), p. 253.

for the opportunity of studying his collection. The following list of fossils shows that the beds certainly belong to the Lower Oolites, and probably to the division of the Inferior Oolite:—

Pholadomya oblita, *Lyc. & Mor.*
Myacites calceiformis, *Phil.*, sp.
——, sp.
Homomya, sp.
Anatina, sp.
Astarte rhomboidalis, *Phil.*
Cyprina Loweana (?), *Lyc. & Mor.*
Cardium, sp.
Cypricardia caudata, *Lyc.*
Lucina, sp.
Arca, sp.
Tancredia angulata? *Phil.*, sp.
—— axiniformis, *Phil.*, sp.
Myoconcha, sp.
Modiola cuneata? *Sow.*
—— imbricata, *Sow.*
Lima duplicata? *Sow.*
Pecten demissus? *Phil.*
Pteroperna, sp.
Gervillia?
Ostrea Sowerbyi, *Mor. & Lyc.*
Exogyra?
Rhynchonella varians? *Sow.*
——, sp.
Plant-remains.
Fucoid? markings.

The promontory of Burghead is formed by beds of coarse sandstones, often conglomeratic, faulted against the Reptiliferous Sandstone. The former, judging from their mineral characters, are not improbably of the same age as the similarly situated beds of Stotfield, but they have not yet, unfortunately, yielded any fossils.

§ 7. *The Middle Oolite.*

The Middle Oolite is very completely represented in Sutherland, by several series of marine beds alternating with estuarine strata, the whole attaining a great thickness. From the marine beds there have been obtained some very interesting and beautiful series of fossils, which enable us to identify several of those clearly marked zones of life which have been distinguished by Dr. Oppel in Suabia*, Professor Hébert in France†, and Dr. Wright in England‡. For a thickness of more than 300 feet we have a succession of purely marine strata, principally clays; and this part of the series perhaps more nearly resembles the equivalent beds in England than do any other strata exposed on the east coast of Scotland.

A. *Zone of* Ammonites calloviensis, *Wright.*—The lowest part of this marine series is formed by a well-marked and everywhere recognizable stratum, which we have already had occasion to mention (the "roof-bed" of the main coal-seam). It is usually about 5 feet thick, though subject to considerable variation in this respect, and consists of a hard more or less calcareous sandstone. In its upper part it is crowded with marine shells, and sometimes passes into a hard shelly limestone; in its lower part it is usually more purely arenaceous, is crowded with plant-remains, and forms a connecting link between the marine strata above and the terrestrial and estuarine beds below. The rock is throughout very ferruginous, being generally of a dark greenish-grey colour when dug under the clays, but weathering to a bright red tint upon the shore.

* Oppel, 'Juraformation' (1856–58) pp. 506, 615, &c.
† Hébert, 'Les Mers Anciennes,' etc. (1857) p. 44.
‡ Wright, "On the Correlation of the Jurassic Rocks of the Côte-d'Or and the Cotteswold Hills," Proc. Cotteswold Club, 1869.

The fossils of this rock, as is the case with those of so many of the Secondary beds of Sutherland, are often much distorted by pressure.

The bed was formerly quarried on the shore, and its more calcareous portions, which are almost wholly made up of shells, burnt for lime; but this use of the rock has long been abandoned. Portions of the bed too have been blown up with gunpowder, where it rises as a reef on the shore, in order that the coal-bed below it might be worked at low water. When the mines at Brora were in operation, considerable quantities of the rock were brought to the surface; and its fossils could then be easily obtained. The only points at which I have myself been able to see this rock and collect its fossils are the Inverbrora reefs and the mine at Strathsteven Cliff.

Sir Roderick Murchison appears to have regarded this bed, from its relation to the series containing the Coals, as the equivalent of the "Grey Limestone" (or "pier-stone" as he calls it) of Scarborough*, a bed which is now very generally admitted to form part of the Inferior Oolite. The true position of the "Roof-bed," however, was more correctly defined by Mr. Alexander Robertson in 1846 to be that of the "Kelloway Rock" of the Yorkshire coast. The annexed list of fossils will serve to satisfactorily establish this correlation, and to demonstrate the close parallelism which exists between this part of the series in Scotland and its equivalents in England.

Fossils of the "Roof-bed" of Brora ("Zone of Ammonites calloviensis" *of Dr. Wright).*

Belemnites Owenii, *Pratt*, var. Puzosianus, *D'Orb.*
—— ——, var. tornatilis, *Phil.*
Ammonites Gowerianus, *Sow.*
—— sublævis, *Sow.*
—— Kœnigi, *Sow.*
——, sp.
Rostellaria composita, *Sow.*
Alaria, sp.
Actæon retusus, *Phil.*
Cerithium muricatum, *Sow.*
Pholadomya Murchisoni, *Sow.*
—— acuticosta, *Sow.*
Anatina undulata, *Sow.*, sp.
Gresslya peregrina, *Phil.*, sp.
Myacites recurvus, *Phil.*, sp.
—— securiformis, *Phil.*, sp.
—— calceiformis, *Phil.*, sp.
Thracia, sp.
Goniomya v-scripta, *Sow.*, sp.
Cardium striatulum, *Sow.*
—— cognatum, *Phil.*
—— Crawfordii, *Leckenby.*
Cardium, spec. nov.
Isocardia tenera, *Sow.*
—— nitida, *Phil.*
Cypricardia, spec. nov.
Unicardium depressum, *Phil.*, sp.
Nucula, sp.
Corbula obscura, *Sow.*
—— oxfordensis, *D'Orb.*
Astarte minima, *Phil.*
Cucullæa concinna, *Phil.*
—— minima, *Leckenby.*
Arca, spec. nov.
Lucina lirata, *Phil.*
—— pulchra, *Bean.*
Trigonia elongata, *Sow.*
—— rupellensis, *D'Orb.*
—— irregularis, *Seeb.*
Modiola cuneata, *Sow.*, var.
—— bipartita, *Sow.*
—— imbricata, *Sow.*
Lima duplicata, *Sow.*
——, sp.
Pteropterna, spec. nov.

* *Vide* Trans. Geol. Soc. 2nd Ser. vol. ii. part 2, p. 297, where Murchison clearly explains that what he identified the roof-bed of Brora with is the bed now usually designated the Grey Limestone of Scarborough.

Gervillia aviculoides, *Sow.*, sp.
Avicula, sp.
Pecten lens, *Sow.*
—— demissus, *Phil.*
—— arcuatus, *Sow.*
—— annulatus? *Sow.*
——, sp.
Gryphæa dilatata, *Sow.*, var. β, *Phil.*
—— bilobata, *Sow.*
Ostrea Marshii, *Sow.*
—— archetypa, *Phil.*
—— Sowerbyi, *Lyc. et Mor.*
Tooth of a Saurian.
Wood (abundant).

The beds lying directly on the calcareous sandstone of the "roof-bed" consist of finely laminated sandy clay, with numerous crushed bivalves, including *Nucula nuda*, Phil., small species of *Pecten*, &c. They abound with specimens of the different varieties of *Belemnites Owenii*, Pratt, and also contain *Ammonites Gowerianus*, Sow., *A. calloviensis*, Sow., var., and *Gryphæa dilatata*, Sow. (small variety). These beds must, from their palæontological characters, be classed with the "roof-bed" in the lowest zone of the Middle Oolite, as representing the Kelloway rock of England.

At the section of Cadh'-an-Righ on the coast of Rosshire, already noticed (p. 125), the "roof-bed" is very distinctly seen, though, like the coal-seam on which it lies, it is greatly reduced in thickness. It consists of a sandy clay passing into a very hard ferruginous and argillaceous sandstone, becoming in places calcareous from the abundance of included fossil shells. The fossils are very numerous, but badly preserved, the substance of the shells being almost always in a soft and decomposed condition. The upper surface of the bed, which is not more than a foot thick, is completely made up of Belemnites of all sizes, crowded together in great profusion. In the abundance of Belemnites which it contains, the rock at Cadh'-an-Righ differs from that at Brora; but there is the most complete correspondence with regard to the rest of the fauna.

Fossils from the "Roof-bed" at Cadh'-an-Righ.

Belemnites Owenii, *Pratt*, var. tornatilis, *Phil.* Very abundant.
——, sp.
Ostrea Marshii, *Sow.*
Gryphæa dilatata, *Sow.* (small form).
Pecten demissus, *Phil.*
—— lens, *Sow.*
Perna quadrata.
Lima pectiniformis, *Schloth.*
Cucullæa.
Trigonia elongata, *Sow.*
—— irregularis, *Seeb.*
Myacites recurvus, *Phil.*, sp.
—— securiformis, *Phil.*, sp.
Gresslya peregrina, *Phil.*, sp.
Serpula.
Wood.

The roof-bed at this place, as at Brora, is covered by a thick series of marine beds, to be more particularly noticed hereafter.

B. *Zone of* Ammonites Jason, *Wright.*—The "roof-bed" at Brora is overlain by a thick mass of argillo-arenaceous strata, crowded with marine fossils. These are the strata pierced in the several coal-shafts. There are great discrepancies in the accounts which we possess of the beds passed through in the two principal shafts; but this may be accounted for (especially when we remember that one of the sections is the result of a boring) by the variable character of the beds, which throughout consist of combinations of sand and clay in varying proportions, so that it is often difficult to decide whether

a particular stratum should be called a sandy shale or an argillaceous sandstone. The thickness of beds passed through in the coal-shafts at Brora was about 230 feet, and adding 70 feet more for the clays seen in the river-cliff above the Fascally or Water-of-Brora pit, we obtain for the total thickness of the argillaceous series above the "Roof-bed" 300 feet. Some of the strata are well exposed in a bluff of the river Brora, a little to the west of the Salmon-cruives, where they are brought up in a double anticlinal fold (see fig. 4, p. 119), and the rocks can be examined by wading the river when it is low; other portions can be seen in a cliff to the eastward, and between the last point and the Water-of-Brora pit; and, lastly, the whole series is displayed, though under somewhat unfavourable conditions, in the reefs on the Inverbrora shore. The lower beds of this series have been shown to belong to the zone of *Ammonites calloviensis*.

In mineralogical characters the different portions of this great series of clays offer very great variations. Sometimes we find dark blue, highly pyritous, shaly clay, with septaria, the characters of which recall the Oxford Clay of England; in other places the beds contain much wood in the form of jet, while nearly all the fossils have disappeared through the decomposition of the pyrites by which they were mineralized; and throughout a considerable part of their thickness the strata consist of finely laminated and very sandy shale crowded with Belemnites, which often attain to a great size, and innumerable specimens of Ammonites, Gasteropoda, and Lamellibranchiata, lying compressed between the laminæ. Occasionally the beds last described pass into hard, fissile, bluish grey sandstone, containing the same fossils, but in a worse state of preservation.

About the geological horizon to which the greater part of this series of argillaceous beds belongs, there is fortunately no reason for entertaining doubt, the fossils, though often badly preserved, being very numerous and highly characteristic.

The Ammonites, which occur in great numbers, nearly all belong to the group of the *Ornati*; but these are associated with a few species of the groups of the *Armati* and *Planulati*. The Belemnites, which are conspicuous alike from their vast numbers and the great size which they attain, belong to the different varieties of *Belemnites Owenii* of Pratt; *Belemnites sulcatus*, Mill., also occurs, but is comparatively rare. Among the Gasteropoda we find *Cerithium muricatum*, Sow., and several species of *Alaria*; while the Conchifera are represented by many species, usually of small size, and often so crushed as to defy specific determination. Oyster-banks do not appear to occur in this series of beds, though scattered specimens of *Gryphæa dilatata*, Sow. (small variety), are sometimes found. Throughout the series wood, often in large masses, and converted into jet, occurs in considerable abundance.

The palæontological characters of these beds clearly indicate that they belong to a geological horizon which has been already studied at many points in Germany, France, and England, and known as the "Ornatenthon" or "braunen Jura *a*" of Quenstedt, the "zones of *Ammonite anceps* and *athleta*" of Oppel and Hébert, and

the "zone of *Ammonites Jason*" of Dr. Wright. Except in the somewhat more sandy character of the beds, this part of the Jurassic series in Sutherland is scarcely distinguishable, either in petrological or palæontological characters, from its equivalents in many parts of Suabia, France, and England.

The principal fossils of these beds, so far as they are known to me, are enumerated in the following list:—

Fossils of the Argillaceous series above the Brora Coal-series, (Ornatus-*clays, Zone of* Ammonites Jason, *Wright*).

Belemnites Owenii, *Pratt*, var. Puzosianus, *D'Orb.*
—— hastatus, *De Blainv.*
Ammonites ornatus, *Schloth.*
—— Jason, *Reinecke.*
—— Gulielmii, *Sow.*
—— Comptoni, *Pratt.*
—— Duncani, *Sow.*
—— Sedgvici, *Pratt.*
—— Lonsdalei, *Pratt.*
—— Elizabethæ, *Pratt.*
—— Bakeriæ, *Sow.*
—— Kœnigi, *Sow.*
—— Reginaldi (?), *Mor.*
—— athleta, *Phil.*
Chemnitzia heddingtonensis?, *Sow.*
Cerithium muricatum, *Sow.*, sp.
Alaria bispinosa, *Phil.*, sp.
——, sp.
Myacites, sp.
Thracia, sp.
Cardium, spec. nov.
Isocardia tenera, *Sow.*
Corbula oxfordensis, *D'Orb.*
Nucula, sp.
Lucina, sp.
Cucullæa, sp.
Avicula, sp.
Pecten, sp.
Gryphæa dilatata, *Sow.*, var.
Ostrea, sp.
Wood (very abundant).

The highest part of the argillaceous series passes up into the marine sandstone strata above by insensible gradations, the arenaceous elements by degrees preponderating over the argillaceous in the composition of the rock. These higher beds, forming the transition between the two series, are generally very unfossiliferous, and yield only an occasional Belemnite (*B. sulcatus*, Mill., or *B. Owenii*, Pratt) or cast of a bivalve. They consist of very sandy clays, with nodular bands of argillaceous limestone, and are well exposed, to the thickness of upwards of 70 feet, in the cutting above the Water-of-Brora (Fascally) coal-pit. The argillaceous limestone here was at one time burnt for lime; and near the same spot the clays were dug for brick-making.

The series of beds just described appears to be brought up again by the transverse fault already noticed to the south of Strathsteven, and is exposed in a number of trial-holes in the brickyard at Clayside, where, however, very few species of fossils have been obtained, these being almost entirely limited to some fragmentary specimens of *Belemnites sulcatus*, Mill., and *Belemnites Owenii*, Pratt. The clay can also be traced, at several points between Clayside and Dunrobin, underlying the marine sandstones to be afterwards more particularly noticed; here, however, they are only seen in a few road-side cuttings and in the burns.

At Cadh'-an-Righ, in Ross-shire, the roof-bed is covered by the following series of beds (Fig. 8, p. 125):—

(*a*) Dark blue, very finely laminated shale, with some bands and flattened

nodules of argillaceous ironstone, containing *Belemnites Owenii*, Pratt (abundant), *Ammonites* (crushed specimens).

(*b*) Somewhat more sandy clays; very imperfectly seen.

(*c*) Thick beds of blue, somewhat sandy shale, with some bands of argillaceous limestone and septaria. Fossils are not abundant: *Gryphæa dilatata*, Sow., (small variety); *Belemnites Owenii*, Pratt.

(*d*) "Roof-bed" of the Coal.

The great sandstone series between these clays and those representing the Coralline Oolite does not appear to be present at Cadh'-an-Righ. It is probable that by a small transverse fracture the "*Ornatus*-clays" of this place are thrown against the clays of the Coralline Oolite of Port-an-Righ.

C. *Zone of* Ammonites perarmatus, *Wright*.—The thick series of beds, with predominating argillaceous characters, which rests upon the roof-bed of the coal, is surmounted by, and passes up into a mass of fine-grained argillaceous sandstones, with marine fossils tolerably abundant, especially in its upper portion. These marine sandstones, which are about 25 feet thick, are well seen on both sides of the river Brora; on the right bank the beds are presented in two exposures, being bent over in an anticlinal, the dip being N. at 12° and S. at 8°. At this point the strata consist of very fine-grained brittle sandstone of a yellowish colour, mottled with streaks of grey. Occasionally certain layers and concretionary patches are found converted into an intensely hard compact quartzite-like rock, with a fine conchoidal fracture.

In these beds fossils are tolerably abundant, but almost always in the condition of casts, and frequently much distorted by pressure. The species which especially characterizes these beds by its great abundance is a *Lucina*, which was confounded by Sowerby with his *Lucina crassa*, a Neocomian form. Wood, sometimes in very large masses and always more or less crushed, abounds in these sandstones. Ammonites, Belemnites, Pectens, and other bivalves occur by no means rarely in these beds. The list of their fossils is as follows:—

Ammonites cordatus, *Sow.*
—— Sutherlandiæ, *Sow.*
—— excavatus, *Sow.*
—— perarmatus, *Sow.*
——, sp.
Belemnites sulcatus, *Mill.*
—— Owenii, *Pratt.*
Gryphæa dilatata, *Sow.*, var.
Exogyra nana, *Sow.*, sp.
Pecten fibrosus, *Sow.*
Pecten vimineus, *Sow.*
—— vagans, *Sow.*
—— demissus, *Phil.*
——, sp.
Pinna lanceolata, *Sow.*
Lucina (crassa, *Sow.*, pars).
Goniomya v-scripta, *Sow.*, sp.
Pholadomya, sp.
Wood.

On comparing this list of fossils with that from the clays below, we find that we have entered a new zone of life. The Ammonites of the group of the *Ornati* have wholly disappeared, and have been replaced by those of the group of the *Cordati*—those of the groups of the *Armati* and *Planulati* persisting, but being represented by other species. Among the Belemnites, *B. Owenii*, Pratt, and its varieties are here very rare, while *B. sulcatus*, Mill., has greatly increased in

abundance and become the predominant form. *Gryphæa dilatata* still continues in existence, but as a distinct and well-marked variety, while a number of Gasteropoda and Conchifera have disappeared, their places being taken by new forms. Other species of longer range lived on through both the periods, while some, which began in far earlier, persisted to much later times. All the palæontological characters of the beds point to the fact that we have reached the horizon known as the "zone of *Ammonites biarmatus*" of Oppel, the "zone of *Ammonites perarmatus* and *cordatus*" of Hébert, and the "zone of *Ammonites perarmatus*" of Wright.

In the gorge of the river Brora, at Fascally, the marine stratum just described is seen to be covered by a great thickness of sandstones, which dip to the east, at first at an angle of 12°; but as we rise in the series this inclination appears to be gradually reduced, till at last it is no more than 4°. These sandstones, the lower beds of which were quarried in order to obtain materials for the wheel-casings and other constructions about the Water-of-Brora coal-pit, must be estimated at not less than 400 feet thick. They yield no traces of marine shells, except in certain thin bands; but they contain much carbonaceous matter in places, with occasional thin coaly seams, and are evidently of *estuarine* origin.

At a height of about 80 feet from the base of this series of sandstones I found a band containing casts of *Pecten*, *Myacites*, and other marine shells, not sufficiently well preserved to enable me to determine the species. About 100 feet higher another marine band occurs, with numerous casts of *Avicula braamburiensis*, Sow., and other shells, too obscure for identification. The highest beds of the sandstone series also contain marine shells in the condition of casts, including *Gryphæa dilatata*, Sow. (large var.), *Pecten fibrosus*, Sow., *Pecten vimineus*, Sow., *Pecten*, sp., *Avicula*, sp., *Myacites*, sp., &c., and form a transition to the marine series above. These beds of sandstone with marine shells are quarried on the left bank of the Brora, a little below the bridge. It is quite possible that, in the thick mass of estuarine sandstones just noticed, other marine bands may occur which have not yet been detected.

The great series of sandstone-strata which we have been describing is bent over towards the north in an anticlinal; this may be traced by observing the dips in the various pits opened on Braamberry and Hare Hills. The lowest marine beds, immediately above the clays, assume at their northern extension a somewhat different character locally, and consist of a hard, brittle, fine-grained sandstone full of casts of fossils. This sandstone has been very extensively dug in the Clynlish or Hare-Hill quarries, and has been employed in the construction of London Bridge and in many local erections, such as Dunrobin Castle, the colossal statue by Chantrey on the top of Beinn-a-Bhraggie, &c. It can be obtained in blocks of great size, is easily worked, and is of a beautiful white colour. In places the rock passes into an intensely hard compact material, like quartzite, which was, in the early part of this century, used by the local militia for making gun-flints, and, as my friend Mr. Joass showed me by a large

series of specimens in the Dunrobin Museum, was extensively employed in prehistoric times as a substitute for flint in making arrow-heads, knives, and other weapons and implements.

The hard sandstone rock, where exposed at the surface on Hare Hill, has retained in a remarkably beautiful manner the striation and grooving impressed upon it by the great Strathbrora glacier, of which this hill at one time evidently formed the northern boundary. Whenever the turf and soil are removed from the surface of the hill, these markings, in a beautiful state of preservation, are revealed to view.

The casts of the exterior and interior of shells, which, however, are often distorted by pressure, are retained in a most perfect manner by this fine-grained rock; and the number of species yielded by it is very considerable. The fauna, however, though more numerous, is evidently the same as that we have already noticed as obtained from the yellow and grey sandstones at Fascally.

The following is the list of the Clynlish or Braamberry-Hill fossils which I have been able to examine:—

Belemnites sulcatus, *Mill.*
—— Owenii, *Pratt.*
Ammonites perarmatus, *Sow.*
—— ——,var.(Edwardsianus,*D'Orb.*).
—— ——, var. (A. Babeanus, *D'Orb.*).
—— ——, var. (A. rupellensis, *D'Orb.*
—— cordatus, *Sow.*
—— excavatus, *Sow.*, var.
—— plicatilis, *Phil.*
—— Achilles, *D'Orb.*
—— Sutherlandiæ, *Sow.*
—— lunula, *Ziet.*
—— anceps albus, *Quenst.* (A. coronatus, *D'Orb.*, var.).
Aptychus, sp.
Pleurotomaria, sp.
Trochus tornatilis, *Phil.*
Turbo funiculatus, *Phil.*
Phasianella, sp.
Chemnitzia, sp.
Pholadomya simplex, *Phil.*
——, spec. nov.
Myacites securiformis, *Phil.*, sp.
—— decurtatus, *Phil.*
—— calceiformis ?, *Phil.*, sp.
Goniomya v-scripta, *Sow.*, sp.
Gresslya.
Mya, sp.
Thracia depressa, *Sow.*, var.
Sowerbya triangularis, *Phil.*, sp.
Lithodomus (crypts).
Tancredia, sp.
Cypricardia, sp.
Cardium (truncatum, *Sow.* ??, pars).
Lucina (crassa, *Sow.* ?, pars).
Cucullæa pectinata ?, *Phil.*
Trigonia Joassi, *Lyc.* (spec. nov.).
Modiola bipartita, *Sow.*
Modiola cuneata, *Sow.*, var.
Perna mytiloides, *Sow.*
Gervillia, sp.
Pteroperna, sp.
Lima læviuscula, *Sow.*
—— pectiniformis, *Schloth.*
——, sp.
Pinna lanceolata, *Sow.*
Avicula braamburiensis, *Sow.*
—— expansa, *Phil.*, var.
Hinnites, sp.
Pecten lens, *Sow.*
—— vimineus, *Sow.*
—— fibrosus, *Sow.*
—— vagans, *Sow.*
—— demissus, *Phil.*
—— inæquicostatus, *Phil.*
—— subfibrosus, *Sow.*
——, sp.
Placunopsis (near jurensis, *Lyc.*).
——, sp.
Gryphæa dilatata, *Sow.*, var. bullata, *Phil.*
Exogyra nana, *Sow.*, sp.
Ostrea Rœmeri, *Quenst.* (O. duriuscula ?, *Bean, in Phil.*).
Terebratula bisuffarcinata, *Schloth.*
Waldheimia, sp.
Acrosalenia (spines).
Equisetites, sp.
Bucklandia Milleriana, *Carr.*
Yatesia Joassiana, *Carr.*
—— crassa, *Carr.*
Casts of wood, often in large masses, and sometimes perforated in all directions by worm-tubes and crypts of Mollusca.

The interesting Cycads derived from these beds, some of which have been described by Mr. Carruthers (*vide* Trans. Linn. Soc. xxvi. 1870, p. 675, pls. 54 & 63) are, like the other vegetables found in the rock, evidently drift timber, which after long floating in the open sea, and being subjected to the borings of numerous marine creatures, became at last buried and fossilized.

Above the Clynlish quarries, where the beds dip N.E. at an angle of from 8° to 9°, various beds of stone, without shells, but with much wood and carbonaceous matter, occur. A pit in these estuarine sandstones, which are evidently the same with those exposed in the gorge of the Brora, is open in Braamberry-Hill Wood; and formerly some of the harder and coarser beds were quarried for millstones. In one of the small openings in the beds of sandstone capping Braamberry Hill (of which a number were opened in order to test the suitability of the ground for a cemetery), stone with casts of shells was exposed, belonging probably to one of the marine bands of the series.

The lower part of the same great series of marine and estuarine sandstones is exposed, though not very favourably for examination, in the reefs at Brora Point.

Near Uppat the same series of sandstones is developed. Some of the pits and roadside sections expose only unfossiliferous sandstones with seams of carbonaceous matter; but in a small pit in the woods near Uppat House, I collected

Pecten vimineus, *Sow.*
—— fibrosus, *Sow.*
—— lens, *Sow.*
Lucina (crassa, *Sow.*, pars).
Modiola bipartita, *Sow.*
Perna mytiloides, *Sow.*
Gresslya, sp.
Wood.

In the deer-forest above Dunrobin Castle, and at an elevation of upwards of 500 feet above the sea-level, several small openings in the wood expose the same series of sandstones. In a pit situated due north of the Castle, to which I was first directed by my friend Mr. Joass, the following species were obtained:—

Ammonites cordatus, *Sow.*
Belemnites sulcatus, *Mill.*
Trochus, sp.
Pecten vagans, *Sow.*
——, sp.
Pinna lanceolata, *Sow.*
Avicula braamburiensis, *Sow.*
——, sp.
Modiola bipartita, *Sow.*
Gervillia.
Lucina (crassa, *Sow.*, pars). (Very abundant.)
Astarte.
Goniomya v-scripta, *Sow.*, sp.
Gresslya, sp.

Another small pit, a little to the north of the last, exposes other white sandstones with a few casts of fossils, including

Chemnitzia, sp.
Pecten fibrosus, *Sow.*
—— vagans, *Sow.*
Perna, sp.
Lucina, sp.

and other bivalves in casts, the species being indeterminable.

Below these sandstone strata, which are also exposed in some

road-side banks, &c., occur the argillaceous beds which are dug at Clayside as already noticed.

A little to the north of Bakkies there is in the deer-forest an old and deep pit, lying N.N.W. from Dunrobin Castle. The strata seen here consist of coarse white or slightly ferruginous sandstone, occasionally passing into grit, with a few pebbles of white quartzite scattered through them. Some of the finer beds are indurated into a kind of pseudo-quartzite. There is about 40 feet of rock exposed in this quarry, the beds dipping E.S.E. 30°. The fossils obtained here consist only of a few very unsatisfactory casts of *Ceromya*?, *Myacites*, or *Homomya*, and *Modiola* (?). I am unable to decide whether these beds belong to the Middle or the Lower Oolite; and the same doubt exists about some of the beds exposed in the neighbourhood of Strathsteven.

These Jurassic sandstones exposed inland often dip at considerable angles, and are greatly disturbed; probably also they are affected by a series of fractures transverse to the great fault which has thrown them against the Palæozoic rocks. In the tract where they occur, which, besides being much masked by drift, is almost wholly covered by woods, it is impossible to trace and map the position of these smaller faults, though the effects produced by them are often sufficiently obvious.

D. *Coralline Oolite.*—The great series of sandstones just described, of which the total thickness cannot be less than 400 feet, is probably, like others of the kind in Sutherland, of estuarine origin; the thin bands containing casts of marine shells, which we have described in it, marking only temporary and local incursions of the sea. It is succeeded, however, by another set of deposits, in which beds with marine characters predominate. These are unfortunately not well exposed, so as to admit of the exact tracing of the succession and thickness of the several strata. At the time of Farey's survey of the district, in 1813, there were a number of pits in which the limestones and clays of this series of beds were dug; and by means of trial-holes he succeeded in tracing their lines of outcrop across the country. Some of these pits appear to have been still open in 1826, when Sir Roderick Murchison made his examination of the district; but they are now all closed. Portions of the series, however, are visible on both banks of the Brora, below the bridge and at Ardassie Point, though, as the rocks are very imperfectly exposed and appear also to be faulted, there is some difficulty in determining their order of succession and thickness.

Lying upon the highest beds of the sandstone series, which, as we have seen, contain numerous casts of marine shells, there occurs a bed of bluish grey sandy limestone. This rock is exposed on the left bank of the Brora, but is now only very imperfectly seen; formerly, however, it was dug and burnt into lime; and the rock is said by Farey to be 12 feet thick. This bed and the other limestones of the series, when exposed at the surface, weather, by the removal of the calcareous matter in solution, into a very soft yellowish brown sandy material, of small specific gravity, formerly used for "rotten-

stone." Masses of these rocks, in a decomposed condition, are found in the Till at the top of the Hare-Hill Quarries. This bed of limestone is crowded with fossils, specimens of the very large variety of *Gryphæa dilatata* being very numerous; *Ostrea gregaria* also occurs in considerable abundance. Ammonites of the group of the *Cordati*, especially *Ammonites excavatus*, Sow., *A. vertebralis*, Sow., and the large compressed variety of *A. cordatus*, Sow., which becomes smooth with age, occur abundantly in this bed. Belemnites are rare, *B. abbreviatus*, Mill., being the only form collected. The genera *Pecten*, *Modiola*, *Cucullæa*, *Pholadomya*, &c. are represented by a number of species. This bed of limestone has been traced in the neighbourhood of Braamberry Hill for some distance; and some lime-pits were opened in it at this point. It may be necessary to mention that it was formerly the custom in the Highland districts to open pits wherever a small bed of limestone was found, and to burn the stone with peats; but the greater facilities of transport have caused the total abandonment of this practice.

The fossils of this limestone-bed are often much distorted by pressure; they are enumerated in the subjoined list.

Fossils of the Argillaceous limestone on the left bank of the Brora (Coralline Oolite).

Belemnites abbreviatus, *Mill.*
——, sp.
Ammonites cordatus, *Sow.*, var.
—— vertebralis, *Sow.*
—— excavatus, *Sow.*
—— Lamberti, *Sow.*
——, sp.
Aptychus, sp.
Pholadomya simplex, *Phil.*
——, spec. nov.
Myacites retusus, *Phil.*, sp.
Anatina undulata, *Sow.*, sp.
Goniomya v-scripta, *Sow.*, sp.
Thracia depressa, *Sow.*, var.
Isocardia, sp.
Cardium, sp.
Cucullæa, spec. nov.
Arca scabrella, *Rig. & Sauv.* (A. quadrisulcata ?, *Sow.*).
—— æmula, *Phil.*
——, sp.
Modiola bipartita, *Sow.*
Modiola cuneata, *Sow.*, var.
Lima læviuscula, *Sow.*
—— concentrica, *Sow.*
Pinna lanceolata, *Sow.*
—— mitis, *Phil.*
Avicula expansa, *Phil.*
Pecten lens, *Sow.*
—— demissus, *Phil.*
—— vimineus, *Sow.*
—— vagans, *Sow.*
—— subfibrosus, *Sow.*
——, sp.
Placunopsis inæqualis, *Phil.*, sp.
——, spec. nov.
Gryphæa dilatata, *Sow.*, var.
Ostrea Rœmeri, *Quenst.*
—— gregaria, *Sow.*
Rhynchonella varians, ? *Sow.*
Serpula, sp.
Fronds of ferns and other plant-remains.
Wood.

The limestones just described are covered by beds of clay, which, on the left bank of the Brora, appear to be thrown out by a fault, so that only a small portion of their thickness is seen; but on the right bank of the river they are well exposed and can be examined behind the curing-house, where the bank has been cut back to make room for the buildings. The beds seen here consist of dark-blue, more or less pyritous, sandy clay, with a few small septaria. Some portions of these clay-beds become extremely arenaceous, and are in-

durated into an imperfect rock; they contain numerous carbonaceous markings; but shells are by no means abundant in them. I collected, however, the following species:—

Belemnites (fragments).
Ammonites Lamberti, *Sow.*
Ostrea gregaria, *Sow.*
Pecten lens, *Sow.*
Pecten vagans?, *Sow.*
—— fibrosus, *Sow.*
—— vimineus, *Sow.*
Cucullæa, sp.

Clays, on this horizon, were at one time dug at several places about Braamberry Hill; but there are no exposures of them at the present time. A small wood here, however, bears the name of Clay-pit Plantation.

It appears probable from the descriptions of Farey, that another bed of limestone, weathering into "rottenstone" and similar to that below the clay-beds, was found above them; but I have nowhere succeeded in finding an exposure of it, so as to collect its fossils.

Above the second limestone bed we have a series of the ordinary white sandstones, with carbonaceous seams and markings. These seem to be similar in every respect to those so common in the district; they appear to exceed 60 feet in thickness, and to be wholly destitute of fossils, and they perhaps constitute a break in the series of marine deposits we are now describing. They are seen on both sides of the estuary of the Brora and in reefs at Ardassie Point.

At the last-mentioned locality the sandstone-beds are seen to be covered by an interesting series of argillaceous limestones of a light-blue colour, which alternate with dark-coloured clays and sandy limestones, yielding many fossils. Some of the beds are crowded with the large expanded form of *Gryphœa dilatata*, Sow.; and *Ostrea gregaria*, Sow., is also abundant. Ammonites of the group of the *Cordati* specially characterize these beds; while those of the group of the *Planulati*, such as *A. plicatilis*, Phil., also occur. The fauna, as will be seen from the annexed list, is not very different from that of the limestone below; many of the fossils are greatly distorted by pressure. The thickness of these beds exceeds 40 feet; they probably constitute the highest portion of the Middle Oolites in this district.

Fossils from the Reefs at Ardassie Point (Coralline Oolite).

Ammonites cordatus, *Sow.*, var.
—— vertebralis, *Sow.*
—— Lamberti, *Sow.*
—— excavatus, *Sow.*
—— plicatilis, *Phil.*
——, sp.
Nerinæa, sp.
Chemnitzia, sp.
Pholadomya simplex, *Phil.*
—— æqualis, *Sow.*
Goniomya v-scripta, *Sow.*, sp.
Myacites retusus, *Phil.*, sp.
Thracia depressa, *Sow.*, var.
Cardium, sp.
Cucullæa, spec. nov.
Arca æmula, *Phil.*
Trigonia corallina, *D'Orb.*
—— monilifera. *Ag.*
Modiola bipartita, *Sow.*
—— cuneata, *Sow.*, var.
Pinna lanceolata, *Sow.*
—— mitis, *Phil.*
Perna Murchisoni, *Forbes.*
Lima læviuscula, *Sow.*
—— concentrica, *Sow.*
Pecten demissus, *Phil.*
—— vagans, *Sow.*
—— lens, *Sow.*

Pecten subfibrosus, *Sow.*
—— vimineus, *Sow.*
——, spec. nov.
Placunopsis inæqualis, *Phil.*, sp.
——, spec. nov.
Gryphæa dilatata, *Sow.*, var.
Ostrea Rœmeri, *Quenst.*
Ostrea gregaria, *Sow.*
Serpula intestinalis, *Phil.*
——, sp.
Spine of Acrosalenia.
Cliona (crypts).
Ferns.
Wood and Plant-remains.

An examination of the faunas of the various limestones and clays above the thick series of estuarine sandstones of the gorge of the Brora shows that they all form part of the same marine series, the beds of white sandstone only marking a partial interruption of the marine conditions. The large series of fossils collected from these marine strata fortunately leaves no room for doubt as to their true geological horizon; the fauna is unmistakably that of the Coralline Oolite of England. The correspondence of the fossils of the Scotch beds with those of the English, in spite of the difference of mineral characters, is very striking.

Thus the Middle Oolite series of Sutherland is seen to be very fully developed, attaining a thickness of at least from 800 to 900 feet, of which about one half is made up of marine strata, and the other half of estuarine.

South of Shandwick Bay, at Port-an-Righ, on the coast of Ross-shire, other beds of the age of the English Coralline Oolite, and differing but slightly in mineral character from those of Sutherland, are found. They consist of dark-blue shales, alternating with and passing into beds of sandy argillaceous limestone. The clays contain some septaria; and towards the middle of the series there are some beds of very hard and compact argillaceous limestone, which weather to a red colour (figs. 6 & 7, pp. 124 & 125).

Fossils are not generally very abundant in these beds; but the hard limestone bands are in places found to be crowded with Ammonites. The most conspicuous fossil is the gigantic expanded variety of *Gryphæa dilatata*, Sow.

The thickness of beds exposed here is not very great, their strike being generally parallel to the shore; the breadth of their outcrop probably does not exceed 100 yards, the dip being from 20° to 30°.

The manner in which these beds are faulted against the Old Red Sandstone, and the curious way in which they are bent, contorted, and broken up by small faults has been already described (see p. 123).

These beds have hitherto been usually classed with the Lias; but the following list of fossils contained in them proves conclusively that their true horizon is that of the English Coralline Oolite.

List of Fossils from the Clays and Limestones at Port-an-Righ, south of Shandwick Bay, Ross-shire (Coralline Oolite).

Belemnites sulcatus, *Mill.*
—— abbreviatus, *Mill.*
Ammonites cordatus, *Sow.*, varieties.
—— excavatus, *Sow.*
Ammonites vertebralis, *Sow.*
—— Reginaldi, ? *Mor.*
—— plicatilis, *Phil.*
—— Achilles, *D'Orb.*

Ammonites, sp.
Perna mytiloides, *Lam.*
Pecten demissus, *Phil.*
Gryphæa dilatata, *Sow.*, var.
Ostrea gregaria, *Sow.*
Serpula, sp.

Although the Middle Oolite strata have not been found *in situ* on the south side of the Moray Firth, yet fragments of them are remarkably abundant in the Boulder-clays of that area. In many places, as in the bed of Loch Spynie, fragments of the coals, unfossiliferous sandstones, &c. of this series abound, and in one case induced the proprietor of the land to undertake a boring in the hope of finding a bed of coal. Fragments of the blue Oxfordian shales, crowded with their characteristic fossils, are also abundant in the Till; and rounded waterworn masses of them are often picked up on the shore. Such masses of Oxfordian beds with fossils have been found, sometimes mingled with fragments of other rocks, at a number of points in Elginshire, at the brickyard of Blackpots, near Banff (where the reconstructed clays are dug for brickmaking), and at the Plaidy cutting, between Macduff and Turriff, in the county of Aberdeen.

In the parish of Urquhart*, in the county of Elgin, there are portions of the Boulder-clay almost made up of fragments of the Oxfordian strata, crowded with the characteristic fossils. These have been very carefully collected by the Rev. James Morrison; and from the specimens preserved in his private collection, and those placed by him in the museums at Elgin and Marischal College, Aberdeen, I have been able to compile the following list:—

List of Oxfordian Fossils from Drifted Masses (Boulders) at Urquhart (Elginshire).

(1) In sandy stone like the "Roof-bed" of Brora:—

Ostrea Marshii, *Sow.*
Gervillia aviculoides, *Sow.*, sp.
Modiola gibbosa, *Sow.*?
Cucullæa concinna, *Phil.*
—— minima?, *Leckenby.*
Isocardia tenera, *Sow.*
Myoconcha, sp.
Myacites recurvus, *Phil.*, sp.
—— calceiformis, *Phil.*, sp.
Gresslya peregrina, *Phil.*, sp.
Perna Murchisonii?, *Forbes.*
Goniomya v-scripta, *Sow.*, sp.

(2) In dark-blue clays:—

Belemnites Owenii, *Pratt.*
—— sulcatus, *Mill.*
Ammonites cordatus, *Sow.*
—— excavatus, *Sow.*
—— Lamberti, *Sow.*
Alaria, sp.
Myacites recurvus, *Phil.*, sp.
Pholadomya, sp.
Goniomya v-scripta, *Sow.*
Trigonia clavellata, *Sow.*, sp.
Modiola bipartita, *Sow.*
—— cuneata, *Sow.*, var.
Gervillia, sp.
Pinna lanceolata, *Sow.*
Perna mytiloides, *Lam.*
Pecten vimineus, *Sow.*
—— lens, *Sow.*
—— fibrosus, *Sow.*
—— demissus, *Phil.*
Placunopsis inæqualis?, *Phil.*, sp.
——, spec. nov.
——, spec. nov.
Gryphæa dilatata, *Sow.*
—— ——, var.
Exogyra nana, *Sow.*
Ostrea Rœmeri, *Quenst.*
—— gregaria, *Sow.*
Serpula intestinalis, *Phil.*

* "On Fossil Remains found at Urquhart, near Elgin," by the Rev. James Morrison, Rep. Brit. Assoc. 1859, p. 263.

Serpula, sp.	Wood.
Crustacean remains.	

Among the Oxfordian fossils obtained from the drifts of Elginshire and the adjoining counties there occur many very interesting and not a few new forms. Among these may be especially mentioned several beautiful species of *Placunopsis*.

The clay of Blackpots, near Banff, yields a number of Oxfordian fossils, such as *Gryphæa dilatata*, Sow., *Belemnites Owenii*, Pratt, and *Belemnites abbreviatus*, Mill.; but with these are mingled Upper-Oolite forms like *Ammonites mutabilis*, Sow., *Lima concentrica*, Sow., and many others. The clay here is certainly a drift deposit, as was shown by Mr. Prestwich* and Hugh Miller†, and not a mass of Oolite *in situ*, as it had previously been considered.

§ 8. *The Upper Oolite.*

The Upper Oolites, which are now for the first time recognized as existing in the northern part of this island, are represented by a great series of strata of shales, sandstones, and grits, the whole of which indicate the prevalence of littoral and estuarine conditions during their deposition. They attain to a thickness of probably not less than 1000 feet, and yield a splendid fauna and flora.

The base of the Upper Oolites is, so far as I know, exposed only at one point in Sutherland, namely the vicinity of Braamberry Hill. At this place, unfortunately, the quarries which formerly existed are now all closed. Above the beds of limestone, already noticed as representing the Coralline Oolite, are some white sandstones with marine shells, including *Ammonites biplex*, Sow., and some other species. I have been able to examine a few fossils which have been preserved from a quarry in these beds near Clynlish; and although the question is not placed altogether beyond doubt by them, yet the balance of evidence is decidedly in favour of our considering them as belonging to the *Upper*, rather than to the *Middle*, Oolites.

Above these marine sandstones are others without fossils, and probably of estuarine origin, which contain some beds of clay, and bands with much carbonaceous matter. These strata are very imperfectly exposed. Perhaps the beds seen to be so curiously contorted in the Clyne-Kirk gorge (see fig. 2, page 118), where they are faulted against the Silurian rocks, belong to this part of the series. The upper part of the sandstones is exhibited north of Allt-na-cuil, where, the strata being bent in opposite directions, the rocks in question are the lowest exposed, and form the apex of a great anticlinal fold.

These unfossiliferous sandstones are succeeded by others containtaining scattered quartz pebbles, and sometimes passing into a very coarse grit or conglomerate; the latter are often crowded with casts of marine fossils, which, however, are usually very imperfectly preserved. Masses of wood, also in the condition of casts, and often of

* Proc. Geol. Soc. vol. ii. p. 545. † Rambles of a Geologist, 1858.

large size, abound, as in the Clynlish stone; but it is composed of much coarser materials than that rock. Slabs also occur, traversed by ripple-markings and worm-tracks, or covered with casts of vegetable fragments and small shells. The strata sometimes greatly resemble the Collyweston, Stonesfield, and similar "slates" of England, and present clear indications of having been deposited under very shallow-water conditions.

These marine beds are best seen at Allt-na-cuil, where, both above and below the waterfall, there are quarries in this rock. They are also seen on the other side of the anticlinal referred to, where a cutting has been made on the Sutherland Railway. This rock forms a valuable building-stone for certain purposes. It is very soft when first quarried, hardens rapidly on exposure, and is very durable. Although of so much coarser texture, it appears, in its power of resisting weathering action, to greatly resemble the celebrated "Roach-bed" of Portland, and, like it, is used for the copings of walls and similar situations.

The fauna of these beds shows that they belong unquestionably to the Upper Oolites, and is as follows:—

Fossils of the Marine Sandstones of Allt-na-cuil &c. (Upper Oolites).

Belemnites obeliscus, ? *Phil.*
Ammonites Eudoxus, *D'Orb.*
—— biplex, *Sow.*, ? var.
—— Achilles, *De Loriol* (non *D'Orb.*).
—— triplicatus, *Sow.*
—— mutabilis, *Sow.*
Natica, sp.
Arca, sp.
Avicula expansa, *Phil.*, var.
Perna subplana, *Etallon.*
Pteroperna, sp.
Pecten demissus, *Phil.*
—— articulatus, *Schloth.*
——, sp.
Hinnites inæquistriatus, *D'Orb.*
Ostrea Rœmeri, *Quenst.*
—— expansa, *Sow.*
—— deltoidea, *Sow.*
Rhynchonella pinguis ?, *Röm.* (very abundant).
—— pectunculoides ?, *Etallon.*
Serpula, sp.
Cidaris, sp. (spines).
——, sp.
Acrosalenia, sp. (spines).
Equisetites, sp.
Wood (abundant).
Fucoid markings ?

These marine beds are overlain by a considerable thickness of strata, of estuarine origin, which are exhibited in the neighbourhood of Allt-Chollie (Colyburn), where, however, they are somewhat obscure, owing to the greatly contorted and crushed condition of the beds, which has been already described (page 118, fig. 3). On the opposite side of the anticlinal, however, between Allt-na-cuil and Lothbeg Point, they are much more favourably exposed for study. They are of very considerable thickness, several hundred feet at least, and consist of alternations of white sandstones, containing only a few plant-remains, and beds of very finely laminated, black, carbonaceous, sandy shales. In the lower part of the series the white sandstones predominate; but as we pass upwards the laminated argillaceous beds become of greater thickness, and at last form the principal part of the mass. In the highest beds, of which admirable sections are exposed at the artificial opening through which the

Lothbeg river now flows to the sea, and in the adjoining railway-cutting, the shales contain a few marine fossils crushed between the laminæ. These are as follows :—

Ammonites alternans, *Von Buch.*	Belemnites obeliscus, *Phil.*
—— flexuosus, *Münst.*	—— spicularis, *Phil.*
—— biplex, *Sow.*	Lima concentrica, *Sow.*, &c.

The Belemnites are nearly always fragmentary. Thus the series of estuarine beds just described graduates up into the marine strata above them.

At the cliff between Lothbeg River and Lothbeg Point the beds just described are seen to underlie and pass up into a set of hard sandstones and grits, alternating with finely laminated black shales. These beds, together with the limestones, with which in their upper part they alternate, were referred by Sir Roderick Murchison to the Lower Oolites, on account of the resemblance of some of the beds to the Forest-marble and Cornbrash of the south of England, though but very slight palæontological evidence was adduced in support of this correlation. The resemblance of some of these beds, in their mineral characters, to the English Forest-marble is certainly sufficiently marked; but this must be regarded as the result only of the similarity of conditions under which the two sets of beds were deposited—the broken condition of the shells, the abundance of wood and plant-remains, and the prevalence of certain genera of Mollusca indicating that in both cases the strata were deposited under littoral conditions. The fauna of these beds, however, like that of the marine sandstones several hundred feet below, yields unmistakable evidence that the whole of these strata, with the estuarine clays and sands between them, must be referred to the Upper Oolite.

This series of grits, shales, and limestones, which can be traced at the mouths of several small ravines at Achrimsdale, Clyne-Milltown, and just north of Kintradwell, is admirably exposed, for a distance of 11 miles, in reefs on the shore, and also in some inland sections, at a great number of points between Kintradwell and Green-Table Point, and even northward in the county of Caithness. Bent into innumerable folds and broken up by many faults, as already described, the beds of this series are repeated again and again along the shore by Garty, Port Gower, Helmsdale, and Navidale. Owing to the superior hardness of the grit-beds of the series, these strata have resisted denudation, and form a number of small headlands, terminating in long reefs of rocks. As already described, these beds are singularly crumpled and broken. The softer shales and interbedded sandstone laminæ have in a great measure yielded to the forces to which they have been subjected; and where they have been planed away many beautiful examples of waved and contorted stratification, accompanied by small hitches or faults, are exhibited with all the clearness and distinctness of a geological diagram. The brittle sandstones, on the other hand, have by the same forces been crushed and broken into fragments; and angular masses of the harder portions of them lie in the greatest confusion, imbedded in a matrix

of sand formed by the grinding-up of the softer portions. In the reefs on the shore these crushed sandstones are sometimes found again completely indurated; and the masses then sometimes resemble walls of the rudest Cyclopean architecture. This apparently *brecciated* condition of the rock must not, however, be confounded with a phenomenon displayed in the same series of strata in their northern development, which is of a totally different character and origin, and will hereafter be particularly described.

This series of beds in many parts yields a considerable number of fossils. The limestones, which are sometimes wholly made up of specimens of *Exogyra nana*, Sow., and *Ostrea* (*Exogyra*) *Bruntrutana*, Thurm., in places contain also a considerable number of other species. Unfortunately, however, the majority of the shells are very fragmentary, or when entire are incapable of removal, owing to the hardness of the matrix and the decomposed condition of the shells. Small Gasteropods and spines of Echinoderms are very abundant; but entire specimens of this latter class seldom or never occur. Very conspicuous, too, in these beds are the gigantic *Rhynchonellæ* (*R. Sutherlandi*, Dav.). Great masses of drifted and waterworn coral, *Isastræa oblonga*, Edw. & Haime, also occur in them. The finely laminated clays contain in many places numerous crushed specimens of *Ammonites*, *Ostrea*, *Lima*, *Avicula*, *Pecten*, &c., and of the remarkable long slender Belemnites (*B. obeliscus*, Phil., and *B. spicularis*, Phil.), which are so characteristic of these beds *. The associated grits contain the same fossils, but in a much worse state of preservation, and nearly always as casts. The limestones of this series were formerly burnt in kilns on the shore at Port Gower, Helmsdale, and Navidale; but this use of them is now abandoned.

Very remarkable and interesting in connexion with these Upper Oolite strata is the large and beautiful flora which they yield. On splitting open some of the fissile grits and sandstones, leaves of Cycadean plants and fronds of ferns are found spread out as in an herbarium. Stems of Cycads, and large masses of wood, with cones and buds of Coniferæ, also occur. This interesting flora was first brought under the notice of geologists by Hugh Miller, by whom some of the more remarkable objects were figured in the last two chapters of his 'Testimony of the Rocks.' Among the beds of limestone, sandstone, grit, and laminated shale are sometimes found much carbonaceous matter, occasionally, as at Gartymore, forming thin and impure seams of lignite.

The thickness of this great series of beds can nowhere be exactly determined. A continuous section near the Allt-gharashtiemore exhibits a succession of over 500 feet; and the whole series is probably not less than twice that thickness.

The following is the list of fossils found in these strata :—

* I have already (page 110) noticed how erroneous information concerning the localities from which certain specimens were derived led to the Belemnites being referred to the Middle instead of the Upper Oolite in Prof. Phillips's Memoir.

List of Fossils from the Limestones, Grits, and Shales of the Upper Oolite of Sutherland (Kintradwell, Garty, Port Gower, Helmsdale, Navidale, &c.).

Plesiosaurus, sp.
Gyrodus Goweri, *Eg.*
Other fish-remains.
Belemnites abbreviatus, *Mill.*
—— obeliscus, *Phil.*
—— spicularis, *Phil.*
Ammonites triplicatus, *Sow.*
—— alternans, *von Buch.*
—— flexuosus, *Münst.*
—— Beaugrandi, *Sauv. et Rig.*
—— biplex, *Sow.*
—— ——, *Sow.*, var.
—— mutabilis, *Sow.*
—— Eudoxus, *D'Orb.*
—— Calisto, *D'Orb.*
—— autissiodorensis, *Cotteau.*
—— Achilles, *De Loriol* (non *D'Orb.*).
Cerithium, sp.
Chemnitzia, sp.
Nerita, sp.
Natica vespa, *De Loriol.*
Pleurotomaria, sp.
Pterocera, sp.
Turbo, sp.
Trochus, sp.
Lithodomus, sp.
Cardium Dufrenoyeum, *Buv.*
—— morinicum, *De Loriol.*
Lucina substriata, *Röm.*
Cucullæa, sp.
Astarte, spec. nov.
Lima concentrica, *Sow.*, sp.
Lima læviuscula, *Sow.*
Avicula expansa, *Phil.*, var.
Placunopsis, spec. nov.
Hinnites inæquistriatus, *D'Orb.*
Pecten vimineus, *Sow.*
——, sp.
——, sp.
Exogyra nana, *Sow.*
—— spiralis, *Goldf.*
Ostrea (Exogyra) Bruntrutana, *Thurm.*
—— Rœmeri, *Quenst.*
—— solitaria, *Sow.*
—— expansa, *Sow.*
—— gessoriacensis, *Sauv. et Rig.*
Rhynchonella Sutherlandi, *Dav.*
——, sp. allied to R. triplicosa, *Quenst.*
——, sp.
Terebratula Joassi, *Dav.*
Waldheimia humeralis, *Röm.*
Serpula Royeri, *De Loriol.*
——, sp.
Cidaris, sp. (spines).
—— —— (spines).
Acrosalenia, sp. (spines).
Isastræa oblonga, *Edw. & H.*
Thamnastræa, sp.
Bennettites Peachianus, *Carr.*
Various Cycads.
,, Ferns.
,, Coniferæ.

The beautiful flora of these beds, the age of which is now placed beyond all question as that of the Upper Oolite, will be made the subject of a critical study by Mr. Carruthers. It will form a new and highly interesting link in the history of vegetable life.

The shales, grits, and limestones just described are covered conformably by a considerable thickness of soft, generally fine-grained sandstone, which in places is indurated into a hard, quartzite-like rock. In their lower part these sandstones are light-coloured, though often stained and banded with ferruginous matter. In their upper part, however, they become very ferruginous, in places passing into an impure ironstone rock, which, by weathering along the joint-planes, assumes the peculiar "cellular" aspect so characteristic of the Northampton Sand of England. As far as I have been able to observe, these sandstones are totally destitute of fossils; and I regard it as probable that, like great portions of the formation which they so greatly resemble in mineral characters, they are of estuarine origin. The rock abounds with spherical cavities, evidently caused by the removal of some foreign matters, probably nodules of iron-pyrites.

The greatest thickness exposed of this sandstone series is about 100 feet, and is seen just north of the Allt-a-ghruan, between the

boat-harbour of Navidale and Dunglass, or Green-Table Point. They are also exposed, but more obscurely, in a small ravine between Wester Garty Burn and Allt-nan-Gabhar (Culgour Burn).

These strata form the highest beds of Secondary age which are exposed *in situ* on the east coast of Scotland.

At Eathie Bay, two miles south of Cromarty, there is a very interesting exposure of the Upper-Oolite rocks. The relations of the Secondary strata at this place to the Silurian and Old Red Sandstone, and the remarkable manner in which they have been rolled and crumpled, and are traversed by pseudo-dykes, has been already described (see pages 126, 127, figs. 9, 10, 11).

These beds have usually been regarded, chiefly on account of their mineralogical character, as of Liassic age; but the details which I shall give concerning their fauna will show conclusively that they exhibit palæontological characters identical with those of the shales, grits, and limestones of Sutherland, which, as we have seen, belong to the Upper-Oolite period.

In lithological characters these beds at Eathie present some slight differences from the contemporary strata to the northward. In the southern of the two patches in Eathie Bay we find beds of hard, very finely laminated shale alternating with bands of argillaceous limestone. The beds of shale often contain nodules of argillaceous limestone and septaria; and these sometimes enclose large and very finely preserved Ammonites. Both the beds of limestone and those of shale, especially the former, are often crowded with fossils. The most abundant forms are:—Ammonites, often of small size, and in prodigious abundance, belonging to the groups of the *Cordati* and *Planulati*; Belemnites, belonging to the remarkably elongated and slender species described by Professor Phillips under the names of *B. spicularis* and *B. obeliscus*; and numerous bivalves, among which *Lima concentrica*, Sow., sp., is specially conspicuous, while *Ostrea Rœmeri*, Quenst., is by no means rare, though generally dwarfed. The abundance of Ammonites, especially of specimens of small size, which occur in clusters containing individuals scarcely exceeding a pin's head in size, is a marked feature. The beds yield also very beautifully preserved fish-remains, saurian bones, and many plants, among which Conifers, Ferns, and Cycads are especially conspicuous. In all these respects we see the close similarity of these beds to the Upper Oolites of Sutherland. On account of the contorted state of the strata at Eathie, it is very difficult to make out their order of succession; but beds of calcareous grit appear on the shore, which apparently underlie the shales and limestones.

The most northern patch at Eathie exhibits strata composed of much coarser materials—namely, sandy black carbonaceous shales, coarse grits, sometimes calcareous and passing into shelly limestones, and sandstones; and these much more nearly resemble the equivalent strata of Sutherland. Marine shells are somewhat rare in them, but they abound in fronds of ferns, wood, &c., and contain also numerous fish-scales.

The presence of a thin carbonaceous band, and the abundance of

plant-remains at Eathie, led to the futile attempts to find coal here which have been already referred to.

Fossils from Eathie (Cromarty), Upper Oolite.

Ichthyosaurus (vertebræ).
Fish-remains (jaws, scales, plates, bones, and teeth).
Aspidorhynchus, sp.
Belemnites spicularis, *Phil.*
—— obeliscus, *Phil.*
—— abbreviatus, *Mill.*
Ammonites mutabilis, *Sow.*
—— ——, var.
—— alternans, *Von Buch.*
—— ——, var.
—— Beaugrandi, *Sauv. et Rig.*
—— flexuosus, *Quenst.*
—— triplicatus, *Sow.*
—— biplex, *Sow.*
Ammonites biplex, *Sow.*, var.
—— Eudoxus, *D'Orb.*
—— Calisto, *D'Orb.*
—— Gravesianus, *D'Orb.*
Turbo, sp.
Avicula, sp.
Lima concentrica, *Sow.*, sp.
——, sp.
Nucula, sp.
Pecten, sp.
Ostrea Rœmeri, *Quenst.*
Conifers (leaves and cones).
Cycads (leaves, buds, stems, &c.).
Ferns (fronds).
Wood.

The marine fossils of the Upper Oolite beds indicate that they agree in age with the middle and lower parts of the English Kimmeridge Clay, the zones of *Ammonites mutabilis* and *A. alternans* of Dr. Waagen.

The general assemblage of fossils presented by these Upper Oolite beds in the north of Scotland more closely resembles that found in some of the French equivalents, in which we have evidence of very similar littoral conditions, than that of the Kimmeridge Clay of England, in which the conditions are somewhat different. The remarkable flora of these beds is of the highest interest, and promises to yield very valuable contributions to our knowledge of the succession of terrestrial plant-life during the Jurassic period, when it shall have been fully studied.

Fragments of the grits and limestones of the Upper Oolite, containing their characteristic fossils, are by no means rare in the Boulder-clay of Elginshire, and have also been detected in Aberdeenshire and Caithness; and masses of blue clay containing the same fossils as the beds at Eathie have been found at Blackpots in Banffshire, Plaidy in Aberdeenshire, and several other localities in the north-east of Scotland.

§ 9. *The Neocomian.*

The question of the former existence of strata of this age in Scotland still remains an open one. Fragments of rock containing the characteristic fossils of the Neocomian have certainly been found enclosed in the Boulder-clay of Elginshire and the adjoining counties; but when we remember a fact which I have pointed out in a previous memoir, namely the great abundance of boulders of rock of this age which are everywhere scattered through the glacial deposits of the North-European area, it becomes us to pause before unhesitatingly referring the fragments in question, which are by no means numerous, to a Scottish origin. On the other hand it must be re-

membered that no portion of the Secondary series in the north of Europe has been almost everywhere so extensively removed by denudation as the Neocomian. From the wide-spread mid-Cretaceous denudation, marking a period of upheaval which preceded that great subsidence during which the *littoral* Upper Greensand and Gault, and the *abysmal* Chalk were deposited, no beds have so greatly suffered as the Neocomian, which were, at the period of that great denudation, the youngest and most recently formed. The proofs of this denudation are familiar to all geologists in the Tourtia of Belgium, the Cambridge Greensand and the Hunstanton Limestone of England; and in a subsequent portion of this memoir I shall have to show what beautiful illustrations of the same great movements are exhibited by the Cretaceous strata of the west coast of Scotland, and in some of the adjoining Hebridean Islands.

While, therefore, we remember the fact that in the North-European district the Neocomian strata, as compared with those of Jurassic age, were originally deposited over more limited areas of sea-bottom, the circumstance of the greater amount of destruction by denudation to which the former, as compared with the latter, have been subjected, should not be lost sight of. The *first* of these considerations, taken in combination with the fact of the comparative rarity of fragments of Neocomian strata in the Scottish drifts, might lead us to decide against the probability of rocks of that age having ever been deposited in the district; if, however, due weight be allowed to the *second* circumstance alluded to, the geologist will hesitate before he accepts as conclusively demonstrated the former absence of the Neocomian beds in a district where even the Jurassic formations have so narrowly, and through such remarkable accidents, escaped total extinction by denudation.

§ 10. *The Upper Cretaceous.*

No such doubt as that which, as we have admitted, still remains concerning the former presence of Neocomian strata in the east of Scotland can be said to exist and to interfere with our adoption of the conclusion that the same area was once covered by strata of the Upper Greensand and Chalk. Although no Upper Cretaceous strata can be detected *in situ* in the north-east of Scotland, yet the vast abundance of the relics of these beds, bearing certificates of their age in their included fossils, which abound in the Boulder-clays of Aberdeenshire, Banffshire, Sutherland, Caithness, and the other counties in the north-east of Scotland, raises the very strongest suspicion that, at a period as recent as the Glacial epoch, great deposits of the Upper Cretaceous still remained unremoved, and supplied numerous boulders to the Till. But when we reflect on what have now been shown to be the relations of the Greensand and Chalk to the other Secondary rocks, alike in Southern Sweden, Western Scotland, the Hebrides, and the north of Ireland, the strong conviction just referred to is converted into something very like certainty.

That in several parts of the county of Aberdeen enormous quan-

tities of chalk flints occur, was first noticed by Dr. Knight, of Marischal College, Aberdeen; the observation, which was confirmed by Dr. Buckland and Mr. (now Sir Charles) Lyell, was published by Sir Roderick Murchison*. In 1841 Mr. Christie pointed out similarly the existence of considerable quantities of chalk flints at Boyndie Bay, Banffshire†. Mr. William Ferguson in 1848–49 showed that over a large tract of Aberdeenshire chalk-flints in great abundance are found in the drift at many points; while at Moreseat, in the parish of Cruden, transported masses of Greensand yielding many fossils also occur‡. Mr. Fergusons's observations were confirmed by Mr. Jamieson§. At the British Association Meeting at Edinburgh in 1850 the late Hugh Miller stated that Mr. Dick, of Thurso, and himself had found numerous boulders of chalk and chalk-flints in the Boulder-clay of Caithness||. In Sutherland Mr. Joass informs me that chalk flints are by no means uncommon in the Boulder-clay; and I have myself seen examples of them containing characteristic chalk fossils.

In 1857 the late Mr. Salter laid before this Society a very interesting account of the fossils of the Cretaceous boulders of Aberdeenshire¶. In that paper he showed that the masses at Cruden appeared to belong to the Upper Greensand, though the fossils were badly preserved and their determination thereby rendered difficult. I may state that I have found boulders of Greensand containing *Exogyra columba*, Sow., and other characteristic fossils of the Upper Greensand in Elginshire and Banffshire, as well as in Aberdeenshire. The chalk-flints were shown by Mr. Salter to contain a considerable number of characteristic British Upper-Cretaceous fossils, together with some forms hitherto only found in the Chalk of Sweden, and others which were quite new.

The great abundance of the relics of the Upper Cretaceous and their wide distribution in the north of Scotland will probably be accepted by all geologists as affording strong grounds for the suspicion that, when the Boulder-clays were formed, large tracts of Upper Cretaceous strata (Chalk and Greensand) were still in existence in the area, and supplied blocks and fragments to the accumulating Glacial deposits.

When we turn our attention in succession to Scania, Morven in Argyllshire, the Isles of Mull and Inch Kenneth, and the counties of Antrim, Londonderry, and Tyrone, in the north of Ireland, we find the evidences of the former existence of a great mass of Upper Cretaceous strata everywhere overlapping the Jurassic deposits. The Upper Cretaceous beds appear at all these points to have consisted of beds of Greensand at the base, in places passing into conglomerates of peculiar and interesting character; these graduate upwards into,

* Trans. Geol. Soc. 2nd ser. vol. ii. pt. 3, p. 365.

† Edin. Phil. Mag. 1841.

‡ Proc. Phil. Soc. of Glasgow, vol. iii. (1848) p. 33; Lond. Edin. and Dublin Phil. Mag. vol. xxxvii. (1850) p. 430; Quart. Journ. Geol. Soc. vol. xiii. (1857) p. 85.

§ *Ibid.* || Brit. Assoc. Rep. (1850), Proc. of Sections, p. 93.

¶ Quart. Journ. Geol. Soc. vol. xiii. (1857) p. 83.

and are overlain by deposits, often of great thickness and sometimes much altered, of white chalk and flints. It seems reasonable therefore to conclude that a like succession of beds prevailed also in this eastern area of Scotland. The general characters, however, of the Cretaceous rocks of Scotland will be described in the Second Part of this Memoir.

IV. *Phenomena presented by the "Brecciated Beds."*

In the previous pages we have described what may be considered the *normal* aspect presented by the Upper Oolite rocks of Sutherland; this is best illustrated by the sections on the shore in the neighbourhood of Kintradwell and Lothbeg. As we proceed northward from these places, however, we find the same strata assuming new and very remarkable characters, which have deservedly attracted much attention and excited great interest among geologists. I allude to the phenomenon first described by Sir Roderick Murchison under the name of the "Brecciated beds of the Ord."

From Garty northward into Caithness the grits and limestones already described as belonging to the Upper Oolites, while in other respects maintaining their normal characteristics, lithological and palæontological, are found, in certain of their beds, to include numerous masses of foreign rocks of various sizes. The frequency of these included blocks appears to increase as we go northward, till in the exposures about the Ord we find the Upper Oolite strata almost wholly made up of fragments of foreign rocks, some of these being of enormous size, crowded together in the greatest confusion, and cemented by a sandy or calcareous matrix.

The features presented by these remarkable rocks are of the most extraordinary character; and the peculiarity of their appearance is greatly heightened by the strangely disturbed and contorted position of their strata, which has already been described. From Garty northward to beyond the Green-Table Point we find reefs composed of these "brecciated beds," which consist of materials that resist denuding influences in a greater degree, perhaps, than any other of the Secondary rocks; and they are formed by the outcrop of beds which exhibit within short distances the most wonderful variations in dip and strike. Thus the appearance presented at low water is that of a number of massive but ruined walls, composed of irregular blocks of stone, often of enormous size; these vast walls sometimes maintain a perpendicular position, but oftener appear as if slipping from their foundations and inclined in different directions and at various angles; they strike in turn to every point of the compass, and often form curves, sometimes long and sweeping, indicative of the great folds of the beds of which they form the outcrop, and sometimes short, sharp, and repeated, marking the violent contortion of those same beds. Occasionally the appearance of bedding is altogether lost, and the shore appears to be made up of a perfect chaos of blocks of stone of the most various proportions and of every con-

ceivable shape, all cemented together by a concrete, mainly composed of crushed and waterworn Oolitic fossils.

This phenomenon must not be confounded with one which has been already described as occurring at Colyburn and elsewhere—namely, that of the crushing up and recementing of the hard sandstones of the Jurassic series. Not to allude to any other of the numerous points of difference between the rocks in the two cases, there are two features which enable us at once to discriminate the one from the other:—

1. At Colyburn and in the similar cases the included fragments are composed of the same rock as the matrix, and both, where fossiliferous, contain the same organic remains of Secondary age; but in the rocks of the Ord the included masses are certainly foreign to the bed, and they contain Palæozoic fossils, while the investing matrix is of a totally different character, and yields Jurassic fossils.

2. In the former cases the masses of included rock are *always* angular; but in the latter, while they are sometimes perfectly angular, at others they present every degree of attrition, and are not unfrequently converted into perfectly well-rounded pebbles.

No one can observe the remarkable appearances presented by these "brecciated beds" of the Ord, without being struck by the evidences they afford of the action of forces of the most potent character.

Sir Roderick Murchison believed that the phenomenon was to be regarded as the result of the eruption in a solid condition of the granite of the Ord, which, as he supposed, produced, at the same time, both the contortion and brecciated condition of the Oolitic beds. But as we have already seen, Sir Roderick did not recognize, although he seems to have strongly suspected, the foreign nature of the included fragments.

Mr. Hay Cunningham, who does not appear to have studied the Secondary beds of Sutherland with that attention and success which characterized his survey of the Palæozoic rocks of the county, put forward a theory which, merely to state, is to condemn. It is that the "brecciated beds" were formed through the breaking up, by the action of waves on the shore, of certain of the Jurassic beds, and that their redeposition and consolidation in the present inclined positions are due to the same agency.

We have already seen that the contorted and greatly disturbed position of the beds near the Ord is due to their proximity to a great line of fracture, and is part of a series of phenomena presented by the Secondary rocks, whether brecciated or not, wherever they are seen in contact with the Primary. We thus arrive at the conclusion that the contortion and the "brecciation" of the rocks are two totally distinct phenomena; and but little consideration of the facts of the case is required to show that, while the latter must have been produced during the deposition of the strata, the former was the result of forces acting subsequently to their formation.

The first to point out clearly, from the evidence of organic remains, that the masses included in the "brecciated-beds" of the Ord are really of foreign extraction and Palæozoic age was the late

Hugh Miller*; he did not, however, attempt to account for the extraordinary phenomenon presented by them.

Professor Ramsay, who visited this interesting coast in company with Sir Roderick Murchison in 1859, informed me that he had been strongly impressed by the conviction that the phenomena presented by the "brecciated beds" could only be accounted for by calling in the agency of ice-action; and he therefore regarded them as possibly affording evidence of the recurrence in early geological times of glacial periods†. It must be confessed, however, that a careful examination of all the facts exhibits some very startling differences between these deposits of Oolitic age, and ordinary Boulder-clays, or, indeed, any glacial deposits of modern date which have yet been described.

In a subject which, I must confess, appears to present such remarkable difficulties, it seems to me that the interests of science will be better served by laying before this Society the results of a careful study and analysis of all the phenomena of the case, than by the advocacy of any particular theory. I am confirmed in this view when I reflect on the enormous and startling difficulties which the phenomena of an ordinary Boulder-clay presented to the older geologists, and the wild speculations into which they were thereby led, and consider at the same time how these difficulties and the resulting theories have been alike dissipated, by modern researches in physical geography and geology. In the hope and confident expectation, therefore, that the study of the forces now acting on the earth, and the changes produced by them, will, at some future time, afford a complete solution of the remarkable phenomena of the "brecciated beds," as it has already done of so many similar difficulties, I proceed to describe all such details of their nature and mode of occurrence as seem to me to be capable of throwing any light on their mode of origin, and which I have been able to observe during a long and careful study of them.

§ 1. *Order of Succession of the beds.*

The "brecciated beds," which exhibit so many evidences of the action of violent forces in their deposition, alternate with others which quite as strikingly indicate the quietest subsidence of fine sediments from still waters as their condition of accumulation. These latter beds consist of very finely laminated shales, with occasional thin seams of sandstone, sometimes with the surfaces of the beds covered with crushed specimens of *Ammonites* and other marine shells; at other times with the laminæ completely covered with vegetable remains, among which occur many beautiful impressions of ferns, cycads, and conifers, while occasionally the vegetable matter is sufficiently abundant to form thin imperfect coaly or lignite seams. At intervals, in the midst of a great mass of these finely laminated strata, which reach a thickness of many hundreds of feet, we find beds

* The Fossiliferous Deposits of Scotland (1854) p. 373; Testimony of the Rocks (1857) pp. 497–8. † Phil. Mag. 4th ser. vol. xxix. (1865) p. 290.

sometimes only a foot or two, at other times 50 or more feet in thickness, made up of blocks of foreign rocks, heaped together in the wildest confusion, and cemented by a sandy or calcareous matrix containing Oolitic fossils. One of the best illustrations of the remarkable alternation of these beds of such very different character is afforded by the section at the opening of the romantic gorge of the Allt-gharashticmore (Gartymore Burn) near the village of Port Gower (see fig. 16).

Occasionally, where the laminated beds have been deposited on the irregular surface formed by the top of one of the "brecciated beds," we see what interference has been produced by the projecting masses of the latter with the usually regular stratification of the former; but as soon as these projections were covered up and masked in clay, the even lamination of the beds is found to be as regular as before.

§ 2. *Age of the "Brecciated beds."*

The investing matrix of the blocks yields many fossils, generally (as is also the case with those of the equivalent strata which are not "brecciated") fragmentary and waterworn. The short and thick Belemnites, and the coarse massive *Ostreæ* have often resisted the forces which have comminuted the other shells. Large masses of waterworn coral, with numerous fragments of wood, also occur in the midst of the heterogeneous assemblage of foreign blocks. The finely laminated beds which alternate with the "brecciated beds," however, yield many fossils in an admirable state of preservation; so that we are at no loss in fixing the age of the beds, which is that of the Upper Oolite. The following fossils are those which most frequently occur in the "brecciated" and associated beds between Garty and the Ord:—

Fossils from the matrix of the "Brecciated beds" of the Ord &c.

Plesiosaurus (vertebræ).
Fish-remains.
Belemnites abbreviatus, *Mill.*
—— (fragments).
Ammonites mutabilis, *Sow.*
—— alternans, *Von Buch.*
—— Eudoxus, *D'Orb.*
—— biplex, *Sow.*
Cerithium, sp.
Turbo, sp.
Nerita?
Lima concentrica, *Sow.*, sp.
Pecten, sp.
Ostrea Rœmeri, *Quenst.*
—— solitaria, *Sow.*
—— expansa, *Sow.*
Rhynchonella Sutherlandi, *Dav.*
Rhynchonella, sp.
Spines of Cidaris and Acrosalenia.
Isastræa oblonga, *Edw. & Haime.*
Leaves (Cycads, Conifers, and Ferns).
Trunks of Conifers and Cycads.

§ 3. *The Matrix of the "Brecciated beds."*

The material which invests and encloses the foreign blocks in these singular strata, varies considerably in character. Usually it is more or less calcareous; but often it is arenaceous, and sometimes argillaceous. Not unfrequently the whole mass of the rock, matrix and included blocks alike, is found traversed by numerous cracks, which are filled with Calc-spar. The great disturbing forces which

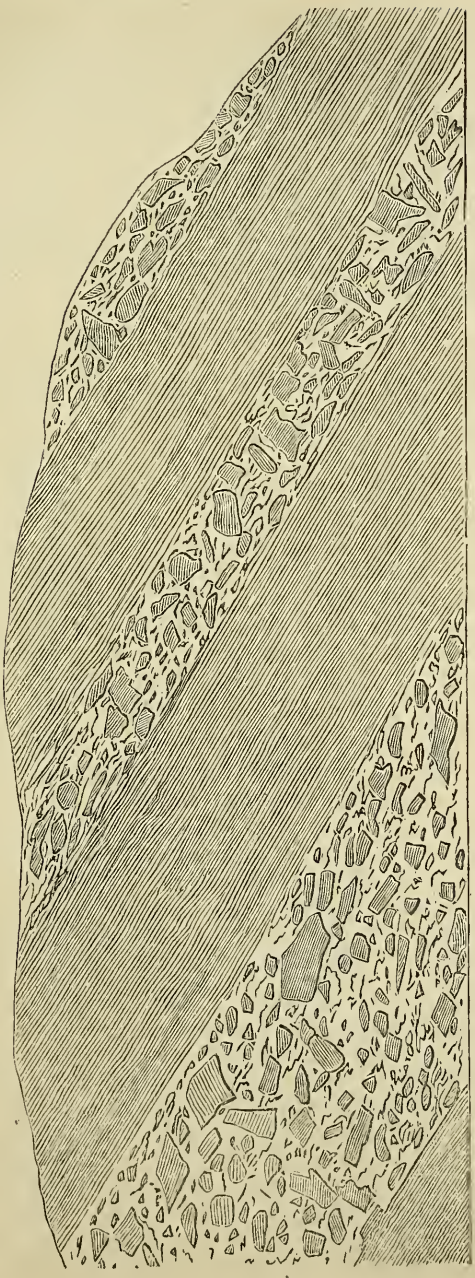


Fig. 16.—*Section at the mouth of the Allt-Gartymore, showing alternation of the "Brecciated beds" (crowded with transported blocks of the Middle Old Red Sandstone), with very finely laminated and lignitiferous sandy shales (Upper Oolite).*

have operated upon these strata since their deposition, and the constant filtration of water through them, at once suggest themselves as the causes of this phenomenon. The calcareous masses of the matrix, which are sometimes sufficiently pure to be burnt for lime, are made up of drifted, waterworn, and comminuted shells, corals, spines of *Cidaris*, &c., with many fragments of wood, and greatly resemble the rock of the Forest-marble. The larger fossils, which remain unbroken, Belemnites, oysters, and corals, usually show signs of having been drifted and waterworn. Among the great extraneous blocks we find numerous trunks of trees completely fossilized; some of these are many feet in length; and with them occur many beautiful stems of Cycads.

§ 4. *The Included Blocks of the "Brecciated beds."*

The careful study of these masses of stone enclosed in the midst of the Upper Oolite strata of Sutherland and Caithness furnishes us with the following details:—

(*a*) *Form.*—Some of the blocks of stone are perfectly *angular*, and on being cleared from the investing matrix exhibit the characters of the surfaces of fracture as clearly and distinctly as if their separation from the parent rock took place but yesterday. These perfectly angular masses constitute the majority of the blocks; but there also exist in great numbers *subangular* fragments of rock, the edges of which exhibit signs of attrition, and which have been evidently subjected, for a limited period, to degrading forces in a stream or on a shore. Lastly, not a few of the fragments, especially among those of smaller size, are completely worn and polished into *pebbles*.

(*b*) *Size.*—The variation of the included blocks in this respect is very remarkable. Sometimes the aspect of a fractured surface of one of the "brecciated beds" is that of an angular gravel, numerous small fragments of foreign rocks being cemented together by sand or shelly detritus. More usually the masses are of much larger size; and, as has been already pointed out, the appearance presented by the beds is that of rough walls, such as are often seen in mountainous districts, composed of angular blocks of the most various size. Occasionally, however, masses are found included in these remarkable "brecciated beds" of such prodigious dimensions as altogether to startle the observer, and bewilder him not a little in seeking for an explanation of the phenomenon. Remarkable examples of this kind are found on the shore opposite to Port Gower, and again between Allt-a-ghruan and Allt-an-aird, south of the Green-Table Point. At the latter locality there is a mass composed of hard light-coloured sandstones, alternating with indurated shales and calcareous flagstones. This mass stands on end, its strata being vertical; and it forms a singular object among the denuded edges of the highly inclined "brecciated beds" in which it lies, its strike being at right angles to theirs, and its dip wholly discordant. The exposed upper edge of this mass measures 20 feet by 10 feet. A little to the south of this is another similar mass, composed of the same materials, the beds of which are also vertical. The continuity

of the mass is not quite so perfectly seen as in the last instance; but it is probably upwards of 40 feet long, and at least 20 feet thick. In the exposed section on the south side of Dunglass (the Green Table) there may be seen, as indicated in the sketch (fig. 5, p. 121), several large included blocks; one of these is about 10 feet long and 4 feet thick.

(*c*) *Position.*—The position of the blocks in the mass is as various as their form and size. In some cases, like those of the great blocks just noticed, the included masses are seen standing on end, with their stratification vertical. In no case does there appear to be any sorting of the materials, which are found heaped together in the wildest confusion, angular and subangular blocks, pebbles, trunks of trees, stems of cycads, masses of coral, shells, shell-detritus, sand and mud.

(*d*) *Markings.*—It may be readily imagined that one of the first channels into which the observations of a student of this singular phenomenon would be directed, in order to detect the cause of transport of these blocks, would be the search for evidence of the action of glacial or floating ice, in the now well-understood and easily recognized polishing, scratching, and grooving which ice-borne rocks usually exhibit. But although innumerable opportunities are afforded for observing the surfaces of the blocks, many of which have evidently not been in the least degree waterworn before being involved in the surrounding and protective matrix, and although I was on the constant look-out for evidence of glacial markings through many weeks during which I studied these beds, yet it must be confessed that *in no single instance was I able to detect a clear and indisputable example of any such markings.*

(*e*) *Material.*—The rocks included as fragments in the "brecciated beds" are somewhat various, consisting principally of calcareous flagstones, often highly micaceous, and exhibiting all the characteristic features of the Caithness Flags of the Middle Old Red Sandstone, with hard sandstones, and indurated, often variegated shales. Occasionally I have found masses which I have been disposed to refer, though with some doubt, to the Silurian strata (altered flagstones) of the district; but blocks of granite or of the conspicuous Old Red conglomerate of the district are, as far as my own observations and those of Sir Roderick Murchison go, altogether absent from the "brecciated beds."

(*f*) *Fossils.*—Hugh Miller was, as already intimated, the first to detect fossils in the included blocks of the "brecciated beds." He records that he found *Osteolepis* and Old-Red-Sandstone fucoids in them; and his testimony, in a matter of this kind, will be admitted to be the most weighty and satisfactory which could possibly be adduced, when we consider the very intimate and exact knowledge which he possessed of the Old Red Sandstone strata of the North of Scotland. His observations I have been able to confirm by the discovery in the blocks in question of very numerous fragments of the Old-Red fishes, preserved in the same manner as is usually the case in the Caithness Flags. Many of these fragments are too small to be

determined; but among them my friend Mr. Joass, who possesses such an intimate acquaintance with the Scottish Old Red Sandstone and its fossils, was able to detect the remains of *Osteolepis* and *Gyroptychius*.

(*g*) *Origin.*—That the great masses of flagstone so abundant in the "brecciated beds" were derived from the Middle Old Red Sandstone or Caithness Flags is thus demonstrated both by their mineral characters and their included fossils. There is every reason to believe that the associated blocks of sandstone and indurated shale came from the same source; indeed, as we have seen, they are found interstratified with the flagstones in some of the great transported masses. We are thus led to conclude that by far the greater number, if not the whole, of these transported blocks were derived from the Caithness Flagstones or Middle Old Red series, the difficulty suggested by Sir Roderick Murchison disappearing, as we have already seen, now that we have demonstrated the enormous faulting and removal of beds by denudation which have taken place in this district subsequent to the deposition of the Jurassic series. The absence of an admixture of foreign blocks from widely different and distant formations is another feature in which the "brecciated beds" differ from those of more modern date, which we now know to have been due to the causes which operated during the Glacial epoch.

§ 5. *General Conclusions as to the Conditions under which the "Brecciated beds" were deposited.*

Refraining, for the reasons already stated, from attempting at the present time to frame any complete theory to account for the formation of these singular beds, I believe we are nevertheless justified, from the consideration of the foregoing facts, in accepting the following general conclusions concerning them:—

1. The whole Jurassic series of Sutherland was deposited in close proximity to land, and large portions of it actually within the estuaries of great rivers. This is as true of the beds of the Upper Oolite as of the other portions of the Jurassic system.

2. The land which bordered the Jurassic sea was not composed of the granites, gneisses, and Old Red conglomerates, which at present constitute so large a portion of Sutherland, but of the calcareous flagstones and associated strata under which the former strata were once deeply buried in this country, and which still form the surface of so large a part of the adjoining county of Caithness.

3. The numerous marine fossils of the Upper Oolites of Sutherland leave no room for doubt that they were accumulated in the sea; but the genera of Mollusca which are most abundant in their fauna, the mineral characters, and the nature of their rock-structure make it equally clear that they were accumulated under decidedly *littoral* conditions.

4. The large and exquisitely preserved flora of these beds indicates that rivers, laden with the spoils of the land, added large and constant contributions to the formation of these same beds.

[*To face page* 194.]

Localities.	Equivalents.
and the ravine north of Allt-nan-Gabhar.	?
avines near, and reefs on the shore), Loth, Gower, Helmsdale, Navidale, and coast to the Ord (in ravines and reefs on the ıths of ravines at Achrimsdale and Clyne	Kimmeridge Clay (lower part).
ally, Doll, Inverbrora, Strathsteven; reefs osite to Salt-pans; Clayside?	
opposite to Salt-pans; coal-pits; Strath- orking.	Lower Oolites of north-east of Yorkshire?
; Hetherington's pit.	
between Brora and Strathsteven.	
he Secondary strata.	
t of Dunrobin Castle.	Lower part of the Middle Lias (Lias γ, Quenstedt).
of Dunrobin Castle.	Upper part of Lower Lias (Lias β, Quenstedt).
ı obin Castle.	Lower part of Lower Lias (Lias α, Quenstedt).
obin Pier.	Rhætic?
t of Dunrobin, Rhives Wood, Golspie -Wood Park, &c.	New Red Marl?
unrobin and Golspie.	Keuper Sandstones?

Formations.	Nature of the Beds.	Approximate Thickness	Characteristic Fossils.	Localities.	Equivalents.
UPPER OOLITE.	Light-coloured sandstone passing into ironstone.	feet. 100+	None.	Allt-a-ghruan, and the ravine north of Allt-nan-Gabhar.	?
	Shelly limestone, alternating with clays. Beds of hard grit, alternating with black carbonaceous shales. (These beds are found to become more and more "brecciated" as we go northwards.)	500?	*Belemnites abbreviatus*, Mill.; *B. oblicuus*, Phil.; *B. apicularis*, Phil.; *Ammonites alternans*, Von Buch; *Am. flexuosus*, Münst.; *Am. trophicetus*, Sow.; *Am. bipler*, Sow.; *Am. antisiodorensis*, Cotteau; *Am. catabilis*, Sow.; *Am. Eudoxus*, D'Orb.; *Am. Calisto*, D'Orb.; *Cerithium*, sp.; *Chemnitzia*, sp.; *Nerita*, sp.; *Lima concentrica*, Sow., sp.; *L. lacteuscula*, Sow.; *Arcula expansa*, Phil., var.; *Placunopsis*, sp.; *Perten*, sp.; *Exogyra nana*, Sow.; *Ex. Brantistana*, Thurm.; *Ostrea Knorri*, Quenst.; *O. solitaria*, Sow.; *O. expansa*, Sow.; *Rhynchonella Sutherlandi*, Dav.; *Hallonia humeralis*, Rém.; *Terebratula Jouani*, Dav.; spines of *Cidaris*, *Acrosalenia*, &c.; *Isastræa oblonga*, Edw. & H.; *Plicatomurex*; *Gyrodus Gowerii*, Eg., and other fish-remains; *Bennettites Peachianus*, Carr., and other Cycads; with Ferns, Conifers, &c.	Kintradwell (ravines near, and reefs on the shore), Loth, Garty, Port Gower, Helmsdale, Navidale, and coast northwards to the Ord (in ravines and reefs on the shore); mouths of ravines at Achrimsdale and Clyne Milltown.	Kimmeridge Clay (lower part).
	Coarse sandstones, grits, and conglomerates.	5+?	Casts of marine shells.	North of Lothbeg River.	"
	Beds of sandstone, alternating with black carbonaceous sandy shale, graduating into beds above.	150+	Plant-remains; *Bel. obliquus*, Phil.; *Am. alternans*, Von Buch; *Am. flexuosus*, Munst.; *Lima concentrica*, Sow., &c.	Cliffs and railway-cuttings between Allt-na-cuil and Lothbeg River; cutting at mouth of Lothbeg River.	"
	Sandstone, often conglomeratic, with casts of shells.	?	*Belemnites oblicuus*, Phil.; *Am. Eudoxus*, D'Orb.; *Am. catabilis*; *Am.*, sp.; *Am. bipler*, Sow., var.; *Arcula expansa*, Phil., var.; *Pteroperna*, sp.; *Hinnites inequistriatus*, D'Orb.; *Perten articulatus*, Schloth.; *Ostrea Knorri*, Quenst.; *Rhynchonella pinguis?*, Rom.; spines of *Cidaris*, *Acrosalenia*, &c.; wood and plant-remains &c.	Allt-na-cuil, stone-pits below and above the cascade.	"
	White sandstone, with plant-markings &c.	?	Plant-remains and wood.	Allt-Choillie, and cliff to the north.	
	White sandstone, with marine shells.	?	*Am. bipler*, Sow.; *Trigonia*, sp., &c.	Old stone-pit near Clynlish Distillery.	
MIDDLE OOLITE.	Beds of bluish-grey argillaceous limestone, with dark blue sandy limestone and clays.	?	*Am. cordatus*, Sow.; *Am. excavatus*, Sow.; *Am. Lamberti*, Sow.; *Am. vertebralis*, Phil.; *Am. planicostæ*, Phil.; *Nerinea*, sp.; *Goniomya v-scripta*, Sow.; *Pholadomya ampla*, Phil.; *P. æqualis*, Sow.; *Thracia depressa*, Sow., var.; *Arca ornata*, Phil.; *Trigonia monilifera*, Ag.; *T. corallina*, D'Orb.; *Cucullea*, sp.; *Modiola hyaritta*, Sow.; *Pinna lanceolata*, Sow.; *Lima lacteuscula*, Sow.; *Perten demissus*, Phil.; *P. vimineus*, Sow.; *P. æquus*, Sow., *P. subfibrosus*, Sow.; *P.*, spec. nov.; *Gryphæa dilatata*, Sow., var., *Ostrea gregaria*, Sow.; *O. Knorri*, Quenst.; *Serpula*; Ferns, wood, &c.	Ardtassie Point; formerly old pits and trial-holes north and west of Brambery Hill.	Coral Rag.
	White ammoniferous sandstones.	?	None.	Ardtassie Point, both sides of Brora Estuary.	
	Dark blue pyritous clays and shales.	?	*Belemnites*, sp.; *Am. Lamberti*, Sow.; *Perten vimineus*, Sow.; *P. æquus*, Sow.; *Ostrea gregaria*, Sow.; *Cucullea*, sp., &c.	South of Brora Estuary; old clay-pit at Clynlish.	Coral Rag
	Grey sandy limestone, weathering into rottenstone, and full of shells	12?	*Bel. abbreviatus*, Mill.; *Am. Lamberti*, Sow.; *Am. vertebralis*, Phil.; *Am. excavatus*, Sow.; *Aptychus*, sp.; *Pholadomya æqualis*, Sow.; *Goniomya v-scripta*, Sow.; *Thracia depressa*, Sow., var.; *Mytilus recurvus*, Phil.; *Anatina undulata*, Sow.; *Isocardia*, sp.; *Arca ornata*, Phil.; *A. scobella*, Rig. et Sanz.; *Modiola hyaritta*, Sow.; *Arcula expansa*, Phil.; *Pinna lanceolata*, Sow.; *Perten subfibrosus*, Sow.; *Perten*, sp.; *Gryphæa dilatata*, Sow., var.; *Ostrea gregaria*, Sow.; *O. Knorri*, Quenst.; *Rhynchonella varians*, Sow.; *Serpula*; wood and plant-remains.	North of Brora Estuary, old limestone-pit; old limestone-pits and trial-holes north and west of Brambery Hill.	"
	White sandstone, conglomeratic in places, with casts of shells.	?	*Gryphæa dilatata*, Sow., var.; *Perten*, sp.; *Arcula*, sp., &c.		"
	White sandstones, with lignite-bands &c.	about 200	Plant-remains and wood.	Gorge of river Brora; reefs at Brora Point, north of Brambery Hill, &c.	
	Soft crumbling sandstones, with casts of shells.	?	*Arcula* and other marine shells (badly preserved).	Below village of Brora, in river-gorge.	
	White sandstone, with lignite-bands &c.	about 100	Plant-remains and wood.	Gorge of river Brora; reefs at Brora Point, Brambery Hill.	
	Sandstone, with casts of shells.	?	*Perten*, *Mytilus*, &c.	Opposite Fascally, in gorge of Brora.	
	White sandstones, with thin coaly seams.	80	Plant-remains and wood.	West end of gorge of Brora, both sides of river.	
	Beds of fine-grained marine sandstone, passing into a kind of white chert, and abounding with beautiful casts of fossils.	25	*Bel. sulcatus*, Mill.; *Am. perarmatus*, Sow. (varieties); *Am. Sutherlandiæ*, Sow.; *Am. cordatus*, Sow. (varieties); *Am. Achilles*, D'Orb.; *Am. Isaaki*, Zirt.; *Am. anceps albus*, Quenst., &c.; *Aptychus*, sp.; *Pleurotomaria*, sp.; *Trochus*, sp.; *Turbo*, sp.; *Chemnitzia*, sp.; *Goniomya v-scripta*, Sow.; *Mytilus*, sp.; *Pholadomya*, sp.; *Lucina*, sp.; *Trigonia Jouani*, Lyc.; *Modiola hyaritta*, Sow.; *Lima lacteuscula*, Sow.; *Lima perforata*, Schloth.; *Pinna lanceolata*, Sow.; *Arcula brachiuriensis*, Sow.; *Perten fibrosus*, Sow.; *P. vimineus*, Sow.; *P. inæquicostatus*, Phil.; *P. æquus*, Sow., &c.; *Placunopsis*, sp.; *Ostrea Knorri*, Quenst.; *Gryphæa dilatata*, Sow.; *Terebratula bisuffarcinata*, Schloth.; *Waldheimia*, sp.; *Bucklandia Milleriana*, Carr.; *Yatesia crassa*, Carr.; *Y. Jouaniana*, Carr; other Cycads, *Equisetites*, Ferns, coniferous wood, &c.; large masses of wood perforated by mollusks &c., and with adhering shells.	Both sides of Brora at Fascally; stone-quarries at Hare Hill and Brambery Hill; pits in deer-forest about Dunrobin?; pits about Uppat and Strathsteven?	Lower Calmreous Grit.
	Grey sandy clays, with nodular limestone.	75	*Belemnites sulcatus*, Mill., &c.	Cliff above coal-pit at Fascally; reefs at Brora.	Oxford Clay in part ("Oxonien-Thon," Quenst.).
	Sandy shales, with few fossils.	80	*Belemnites*.	Coal-shafts and borings, and reefs on shore at Brora,	
	Bituminous and pyritous shales, with septaria.	55	*Belemnites*, very abundant (most of the fossils destroyed by the decomposition of pyrites).	cliff north of river Brora.	
	Hard sandy shales, passing into argillaceous sandstone.	25	*Bel. Owenii*, Pratt; *Bel. hastatus*, De Blainv.; *Ammonites ornatus*, Schloth.; *Am. Jason*, Rein.; *Am. Duncani*, Sow.; *Am. Rakeriæ*, Sow.; *Am. Koenigi*, Sow.; *Am. athleta*, Phil.; *Chemnitzia Heddingtonensis*, Sow.; *Cerithium excavatum*, Sow.; *Alaria bipunctata*, Phil.; *Mytilus*, sp.; *Thracia*, sp.; *Isocardia tenera*, Sow.; *Corbula Oxfordensis*, D'Orb.; *Nucula*, sp.; *Cucullea*, sp.; *Lucina*, sp.; *Arcula*, sp.; *Perten*, sp.; *Gryphæa dilatata*, Sow.; wood in turn of jet.	Bluff on north side of River Brora, shafts and borings of coal-pits; reefs near Brora Point; Clynside.	
	Black, finely laminated shales, with bands of septaria, and beds made up of crushed shells.	70	At the base numerous small bivalves; *Nucula nuda*, Phil.; *Perten*, sp.; with *Ammonites Gowerianus*, Sow., *Am. Calloviensis*, Sow., and *Belemnites*.	Reefs on shore near Brora, coal-pits.	Oxford Clay in part and Kelloway Rock.
	Calcareous sandstone, passing into a limestone in its upper part ("Roof-bed").	5	*Bel. Owenii*, Pratt (varieties); *Am. Gowerianus*, Sow.; *Am. subclavis*, Sow.; *Am. Koenigi*, Sow.; *Rostellaria compacta*, Sow.; *Alaria*, sp.; *Cerithium muricatum*, Sow., sp.; *Natica reticosa*, Phil.; *Buccinum?*; *Pholadomya Murchisoni*, Sow.; *P. acuticosta*, Sow.; *Anatina undulata*, Sow.; *Mytilus recurvus*, Phil.; *M. calciformis*, Phil.; *Gresslya peregrina*, Phil.; *Goniomya v-scripta*, Sow.; *Cardium striatulum?*, Sow.; *C. cognatum*, Phil.; *Isocardia tenera*, Sow.; *I. minima*, Phil.; *Cucullea concinna*, Phil.; *C. cancellata*, Leckenby; *Arca*, spec. nov.; *Lucina pulchra*, Beau.; *L. lirata*, Phil.; *Corbula oxfordensis*, D'Orb.; *Astarte minima*, Phil.; *Trigonia elongata*, Sow.; *T. impolitæa*, D'Orb.; *T. irregularis*, Sceb.; *Modiola cuneata*, Sow.; *M. imbricata*, Sow.; *Lima duplicata*, Sow.; *Pteroperna* spec. nov.; *Gervillia acuticostata*, Sow.; *Perten lens*, Sow.; *P. demissus*, Phil.; *Gryphæa dilatata*, Sow.; *Ostrea Marshii*, Sow., &c.; wood.	Coal-pits of Fascally, Doll, and Inverbrora; reefs on shore opposite to Salt-pans; cliff at Strathsteven (coal-works).	Kelloway Rock.
LOWER OOLITE.	Main seam of coal.	5 feet 6 inches	*Equisetites columnare*, Brongn.	Coal-pits, Fascally, Doll, Inverbrora, Strathsteven; reefs on shore opposite to Salt-pans; Clynside?	
	Dark shales, with thin coal-seams, shelly bands, bone-bands, &c.	feet. 20	*Unio*, *Cyrena*, *Perna*, *Ostrea*, *Cypris*, &c.; scales and teeth of *Lepidotus*, *Seminotus*, *Pholidophorus*, *Hybodus*, *Acrodus*, &c.; *Equisetites*, and other plant-remains.	Reefs on shore opposite to Salt-pans; coal-pits; Strathsteven coal-working.	Lower Oolites of north-east of Yorkshire?
	Variegated shales and impure fire-clays; thin coal-seams, bands and nodules of argillaceous limestone.	90	*Cyrena*, *Ostrea* (dwarfed), &c.	Reefs on shore, Hetherington's pit.	
	White sandstones and shales.	110+	Occasional *Cyrenæ*, bands with casts of marine shells, *Mytilus*, *Trigonia*, &c.	Reefs and cliffs between Brora and Strathsteven.	

The relation of the above strata to the Lias is nowhere seen in the county of Sutherland, owing to the great transverse faults which have affected the Secondary strata.

LIAS.	Beds of dark blue, highly micaceous clay, with numerous septaria.	80+	*Ammonites brevispina*, Sow.; *Am. Jamesoni*, Sow.; *Am. capricornus*, Quenst., var.; *Bel. acutus*, Mill.; *Bel. elongatus*, Schloth.; *Cardinia attenuata*, Sow., sp.; *C. lanceolata*, Stutch.; *Hippopodium ponderosum*, Sow.; *Pholadomya decorata*, Ag.; *Pinna ovoides*, Rom., sp.; *Unicardium cardioides*, Phil., sp.; *Cardium truncatum*, Sow.; *Lima pectinoides*, Sow.; *Cucullæa Munsteri*, Goldf.; *Modiola scalprum*, Opp.; *Pinna folium*, Y & B.; *Perten hamus*, Nyst, *P. subtextis*, Phil.; *Plicatula spinosa*, Sow.; *Gryphæa cymbium*, Lam., var.; *G. obliqua*, Sow.; *Terebratula punctata*, Sow.; *Rhynchonella smithii*, Quenst.; *Penlacrinus moniliferus*, Quenst.	Reefs north-east of Dunrobin Castle.	Lower part of the Middle Lias (Lias γ, Quenstedt).
	Beds of impure limestone, alternating with shale; the former full of shells.	110	*Am. oxynotus*, Quenst.; *Am. capricornus*, D'Orb.; *Bel. acutus*, Mill.; *Pholadomya ambigua*, Sow.; *Tancredia*, sp.; *Hippopodium*, sp.; *Cardinia hybrida*, Sow., sp.; *C. lanceolata*, Stutch., sp.; *Hinnites*, Rom., sp.; *Unicardium cardioides*, Phil., sp., *Modiola*, spec. nov.; *Perten subtextis*, Phil.; *P. lamellosus*, Ziet.; *P. textorius*, Schloth.; *Pinna Hartmanni*, Ziet.; *Lima pectinoides*, Sow.; *L. punctata*, Sow.; *L. Konnarkana?*, Chap. et Dew.; *Ostrea?*, sp.; *Gryphæa obliqua*, Sow.; *Rhynchonella tetraedra*, Sow.; *R. cornubita*, var. *triplicata*, Phil.; wood.	Reefs north-east of Dunrobin Castle.	Upper part of Lower Lias (Lias β, Quenstedt).
	Beds of sandstone, with bands containing vertical plant-markings.	?	Casts of marine shells (*Perten* &c.) in upper part.	Reefs below Dunrobin Castle	Lower part of Lower Lias (Lias α, Quenstedt).
	Beds of sandstone and shale, with coal-seams.	about 400	Plant-remains		
	Beds of sandstone and conglomerate.	?	None?	Reefs near Dunrobin Pier.	Rhætic?
TRIAS.	Concretionary cream-coloured limestones, passing into chert.	10–20?	None.	Reefs south-east of Dunrobin, Rhives Wood, Golspie Burn, Quarry Wood Park, &c.	New Red Marl?
	Beds of yellow and light-coloured sandstone.	40–50 seen.	None.	Reefs between Dunrobin and Golspie.	Keuper Sandstone?

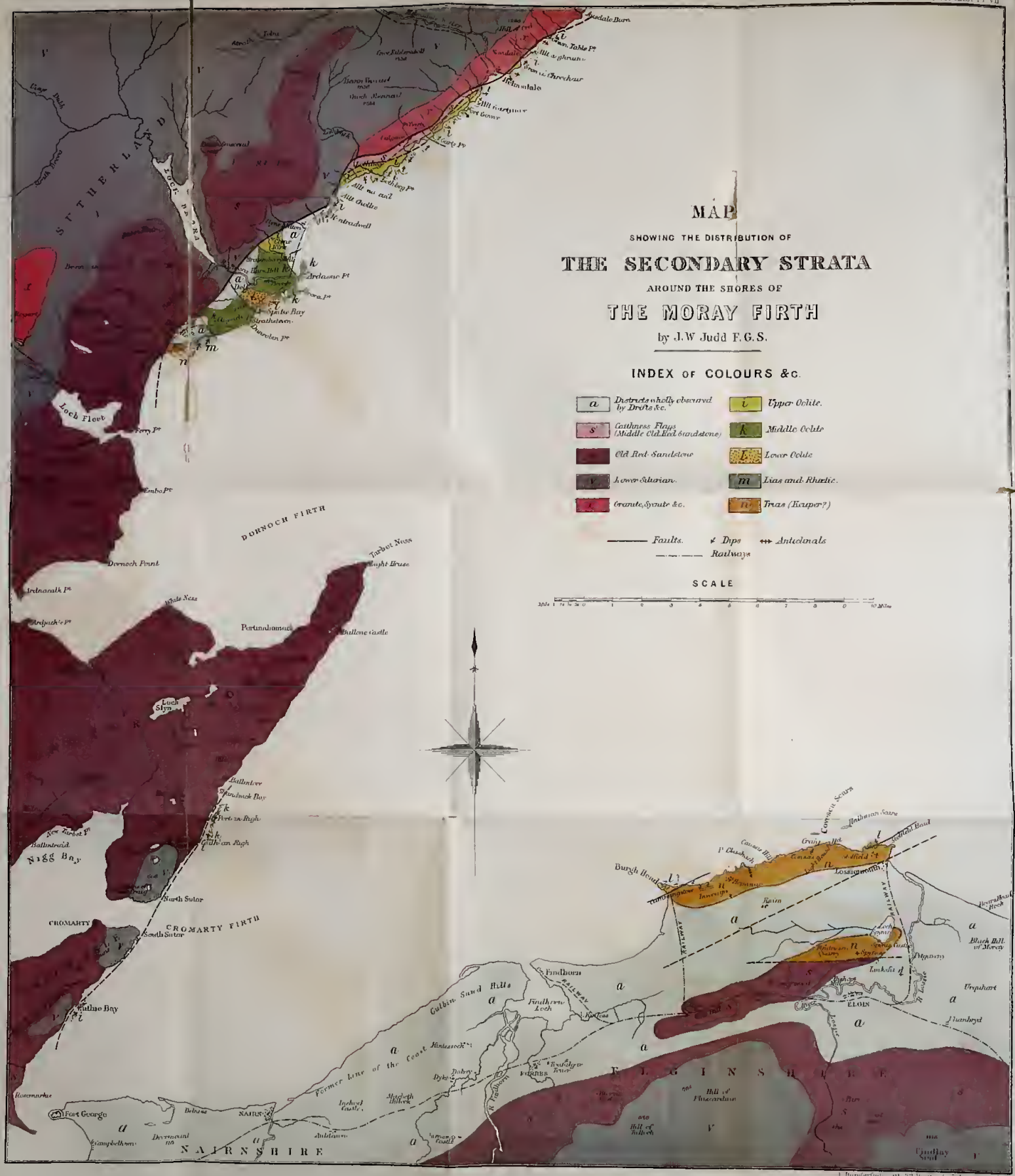
[*To follow* Table I.]

		seen *in situ* in other counties.	Transported masses in the drifts, &c.
CRETACEOUS.	Ch		Masses of chalk-flints in Aberdeen, Banff, Sutherland, &c.
	Up a Ne		Fragments of greensand with fossils (Elginshire, Aberdeenshire, &c.). ?Elginshire, Aberdeenshire (Urquhart, Plaidy, &c.). Boulders, Lossiemouth (Elginsh.) &c.
		Green-Table Point (Caithness).	„ Elginshire, Banffsh. (Blackpots, &c.).
	Up	? (Cromarty).	„ Caithness, Morayshire, &c. „ Elginshire. ? ?
		an-Righ (Ross).	„ Elginshire (Urquhart &c.), rolled fragments on shore, &c. „ Elginshire, Banff, &c.
	Mi		„ Urquhart (Elginshire). ? ? „ Elginshire.
JURASSIC.		-an-Righ (Ross).	„ Elginshire, and in rolled fragments on shore.
		„	„ Elginshire, &c.
		„	„ Loch Spynie (Elginsh.), &c.
		„	? ? ? ?
	Lo	eld and Burghead? (Elginsh.).	„ Elginshire, &c.
		?	„ „
	Mi		Fine-grained micaceous sandstone, Lhanbryd, Loch Spynie, and other localities in Elginshire, &c.
	Lo		Boulders, Loch Spynie &c. (Elginsh.). „ Kaim, Inverugie, &c. (Elg.). ? ?
TRIAS.	Ri		? ?
	Ke	rty rock of Stotfield," Elginsh.	Drifts of Elginshire, on shore, &c.
		tiliferous Sandstones," „	? ?

[*To follow* Table I.]

TABLE II.—*Comparative View of the Secondary Rocks of the East Coast of Scotland.*

	Formations.	Groups.	Strata seen *in situ* in Sutherland.	Nature.	Approximate Thickness in feet.	Strata seen *in situ* in other counties.	Transported masses in the drifts, &c.
CRETACEOUS.	CHALK.						Masses of chalk-flints in Aberdeen, Banff, Sutherland, &c.
	UPPER GREENSAND and GAULT.						Fragments of greensand with fossils (Elginshire, Aberdeenshire, &c.).
	NEOCOMIAN.						?Elginshire, Aberdeenshire (Urquhart, Pluidy, &c.).
			x. Light-coloured and ferruginous sandstones passing into impure iron-stones.	Estuarine.	100+		Boulders, Lossiemouth (Elginsh.) &c.
JURASSIC.	UPPER OOLITE.	Zones of *Am. mutabilis* and *Am. alternans* of Waagen (Kimmeridge Clay, lower part).	*y.* Coarse shelly limestones. *x.* Finely laminated carbonaceous shales with shelly grits. } "Brecciated beds."	Marine. Marine and Estuarine.	500+	N. of Green-Table Point (Caithness). Eathie (Cromarty).	,, Elginshire, Banffsh. (Blackpots, &c.). ,, Caithness, Morayshire, &c.
			w. Coarse sandstones, grits, and conglomerates (casts of marine shells).	Marine.	50?		,, Elginshire.
			v. Coarse sandstones with plant-remains, coaly seams, &c.	Estuarine.	150+		? ?
			u. Sandstones with marine shells.	Marine.	?		? ?
		Coralline Oolite.	*t.* Sandy and argillaceous limestones, clays, and sandstones.	Marine, &c.	200?	Port-an-Righ (Ross).	,, Elginshire (Urquhart &c.), rolled fragments on shore, &c.
		,, ,,	*s.* A great mass of coarse sandstones with coaly seams (several marine bands).	Estuarine.	400		,, Elginshire, Banff, &c.
	MIDDLE OOLITE.	Zone of *Am. perarmatus*, Wright (Lower Calcareous Grit).	*r.* Marine sandstones, fine-grained, graduating into beds below.	Marine.	25		,, Urquhart (Elginshire).
			q. Sandy shales, with few fossils.	Marine.	150		? ?
		Zone of *Am. Jason*, Wright (Oxford Clay, part).	*p.* Blue pyritous and laminated shales passing into sandstones.	Marine.	80		,, Elginshire.
			o. Black laminated shales with septoria and shelly bands.	Marine.	70	Cadh'-an-Righ (Ross).	,, Elginshire, and in rolled fragments on shore.
		Zone of *Am. calloviensis*, Wright (Kelloway Rock).	*n.* Calcareous sandstone crowded with fossils ("Roof-bed").	Marine.	5	,,	,, Elginshire, &c.
	LOWER OOLITE (and UPPER LIAS?).		*m. Coal*, with band of pyrites in its midst.	Estuarine.	3½	,,	,, Loch Spynie (Elginsh.), &c.
			l. Variegated estuarine clays, bands of estuarine shells, impure *coals*, &c.	Estuarine.	110	,,	? ?
			k. White sandstones with subordinate beds of shale.	Estuarine.	100+	,,	? ?
		Great Oolite?	*j.* Sandstone with casts of marine fossils.	Marine.	?	Stotfield and Burghead? (Elginsh.).	,, Elginshire, &c.
			i. Sandstones and shales.	Estuarine.	? very great.	,, ?	,, ,,
			[Interval not represented in the Sutherland sections.]				Fine-grained micaceous sandstone, Lhanbryd, Loch Spynie, and other localities in Elginshire, &c.
	MIDDLE LIAS.						
	LOWER LIAS.	Zone of *Am. Jamesoni*, Oppel.	*f.* Thick mass of blue micaceous clays with many fossils.	Marine.	80+		Boulders, Loch Spynie &c. (Elginsh.).
		Zones of *Am. raricostatus* and *Am. oxynotus*, Oppel.	*e.* Sandy limestones alternating with blue clays; many fossils.	Marine.	100		,, Kain, Liverugie, &c. (Elg.).
			d. Alternations of sandstone and shale, with two (or more) thin seams of coal (no marine fossils).	Estuarine.	400		? ?
TRIAS.	RILETIC?	Zone of *Avicula contorta*, Wright.	*c.* Thick series of conglomerates, sandstones, and grits, sometimes calcareous (contains pebbles of *b* and *a*).	Marine?	50+		? ?
	KEUPER?		*b.* Concretionary, cream-coloured limestones passing into chert &c.	Lacustrine?	10 to 20?	"Cherty rock of Stotfield," Elginsh.	Drifts of Elginshire, on shore, &c.
			a. Beds of yellow and light-coloured sandstone.		50+	"Reptiliferous Sandstones," ,,	? ?



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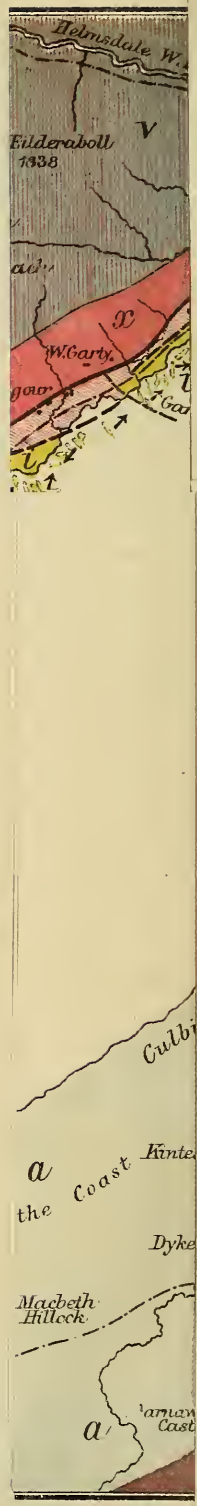
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5. The alternation of the "brecciated beds" with the finely laminated and quietly deposited strata, and the confused arrangement of the blocks in the latter, their admixture with trunks of trees, stems of cycads, and other plant-remains, seem to indicate that the quiet deposition of the semi-estuarine beds was interrupted by the occasional occurrence, in the rivers just alluded to, of floods of the most violent character. These appear to have swept angular masses, just separated from their parent rock by frosts or landslips, subangular masses which had lain for a time in the course of the streams, and the rounded pebbles of the river-beds, along with trunks of trees torn from their banks, all in wild confusion out to sea, where they were mingled with the sea-derived materials of the shell-banks and shoals.

6. The continuity which is preserved in masses of enormous dimensions composed of a number of strata, seems to suggest the action of some agency in their transport beyond that of floods; and the only one which we are at present acquainted with capable of thus buoying up these enormous masses unbroken to their destination, appears to be *ice*. Possibly, too, it will be difficult to account for the occurrence of floods of such extraordinary violence as those we have shown must have occurred, except upon the supposition that the country was subject to those vicissitudes incident to the presence of glaciers in neighbouring mountains.

7. The total absence of glacial polishing and striation from the surfaces of the transported blocks, and the abundance of a splendid flora abounding in cycads, ferns, and large trees on the adjoining land, to say nothing of the characters of the abundant marine fauna, entirely preclude the idea that these masses were actually heaped together by glaciers which came down to the sea-level.

8. The local character of these blocks, and the absence of far-travelled boulders, alike indicate that these accumulations could not have been formed by the stranding and melting of icebergs.

Here then we pause, in the expectation that future researches in the physical geography of some as yet little-studied region may demonstrate the existence, in the same combination, of those conditions which we have shown must have been present during the deposition of the wonderful "brecciated beds" of the Ord.

EXPLANATION OF THE MAP. PLATE VII.

As the basis of this map the Admiralty Chart of the Moray Firth, on a scale of two geographical miles to an inch, has been employed, the Ordnance Survey of this part of Scotland not being yet completed. In drawing the boundaries of the Palæozoic rocks, I have, in the main, followed the older maps of Macculloch, Hay-Cunningham, and Martin, adopting, however, many corrections from more recent authorities, such as Prof. Nicol, Murchison and Geikie, and the Rev. J. M. Joass. The geological lines for the Mesozoic formations I have myself supplied. No attempt has been made to represent, on the southern side of the Firth, the complicated relations of the Primary and Secondary strata which have been brought about by the great faults; even if it were practicable to trace these relations with any approach to certainty in a district so covered with drift-deposits, it would be impossible to exhibit them on a scale so small as that of this map.

Note *on some* Brachiopoda *collected by* Mr. Judd *from the* Jurassic Deposits *of the* East Coast *of* Scotland. By Thomas Davidson, Esq., F.R.S., F.G.S.*

[Plate VIII.]

Among the Brachiopoda collected by Mr. Judd from the Jurassic deposits of the north of Scotland we find four species particularly worthy of notice. Two are, as far as I am aware, quite new, and two new to Great Britain. Three of the four have likewise been obtained from the Upper Oolite or equivalent of the Kimmeridge Clay; and this is the more remarkable since the species of Brachiopoda recorded from that formation are comparatively few.

Rhynchonella Sutherlandi, n. sp. Pl. VIII. figs. 1, 2.

Shell transversely oval, wider than long, greatest breadth about the middle. Ventral valve convex; sinus wide, moderately deep; foramen rather small, placed under the incurved extremity of the beak, surrounded and slightly separated from the hinge-line by a deltidium of small dimensions. Dorsal valve deeper and more convex than the opposite one, sometimes very gibbous, and divided into three portions, the central one being formed by a wide mesial fold. Surface of each valve marked with from sixteen to thirty large angular ribs, of which from six to twelve occupy the fold, five to thirteen the sinus. Proportions very variable. A large specimen measured $2\frac{2}{5}$ inches in length by $2\frac{6}{8}$ inches in breadth.

Obs. This is one of the largest species of the genus with which I am acquainted, having been exceeded in size, as far as I am aware, only by the *R. multicarinata*, Lam., = *Terebratula peregrina*, v. Buch, and the *R. inconstans speciosa* of Münster. In external shape and character it most nearly approaches the smaller *R. Renauxiana*, D'Orb., from the Upper Neocomian of the south of France. It varies likewise very much in the number and strength of its ribs; but this is a feature common to almost every species of the genus.

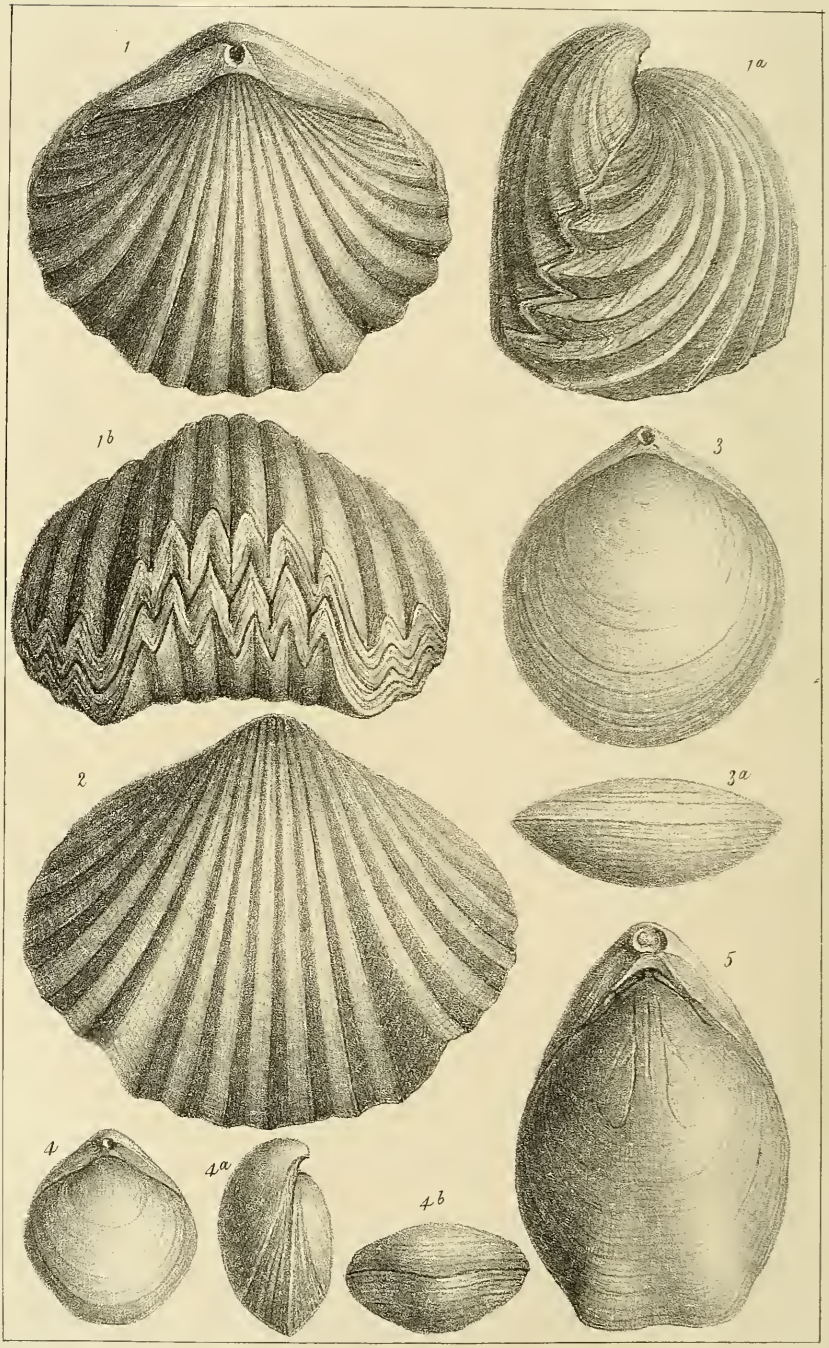
R. Sutherlandi appears to be a common shell in the grey Upper Oolite limestone at Garty, in Sutherland, the specimens figured having been communicated by the Rev. J. M. Joass from the Dunrobin Museum. We have named it after His Grace the Duke of Sutherland, in humble appreciation of the service he is rendering to science by the formation of a local museum at Dunrobin.

Terebratula Joassi, n. sp. Pl. VIII. figs. 3, 3*a*.

Shell longitudinally oval, broadest anteriorly, slightly tapering at the beak. Valves very moderately convex, without fold or sinus; beak small, incurved and truncated by a circular foramen, slightly separated from the hinge-line by a deltidium in one piece. Dorsal valve sometimes very much flattened. Surface smooth, marked by concentric lines of growth. Length $1\frac{6}{8}$ inch, breadth $1\frac{1}{2}$ inch, depth $\frac{5}{8}$.

Obs. The species which this shell most nearly approaches is the

* Read March 12, 1873.



Thos Davidson. del. et. lith.

M&N Hanhart. imp

SCOTTISH JURASSIC BRACHIOPODA.

T. ovoides, Sow.,=*T. rex*, Lankester; but it differs from it in the absence of any mesial depression in the dorsal valve, and carination in the ventral one. It was found by Mr. Judd in the Upper Oolite of Garty, Sutherland; and I have much pleasure in naming it after the Rev. J. M. Joass, who has devoted so much attention to the Jurassic formations of that part of Scotland.

Terebratula (or Waldheimia) humeralis, Rœmer. Pl. VIII. figs. 4*a*, 4*b*.

Specimens agreeing in every particular with the *T. humeralis*, Rœmer (of which an excellent description and figures will be found at p. 414 of the 'Description Géologique et Paléontologique des étages Jurassiques de la Haute Marne,' by Messrs. P. de Loriol and E. Royer), appear to be common in the Upper Oolite of Garty, in Sutherlandshire. In France, according to the palæontologists above named, it occurs in the "Calcaire à Astartes" or upper portion of the Coralline Oolite, a zone underlying the Kimmeridge. It had not been hitherto recorded as a British species.

Terebratula bisuffarcinata, Schlotheim. Pl. VIII. fig. 5.

Internal casts of this species are extremely abundant in the Coralline Oolite, or zone of *Ammonites perarmatus*, Lower Calcareous Grit of Braamberry Hill in Sutherlandshire. In 1862 I mistook it for *T. perovalis*, which some examples of Schlotheim's species much resemble; but while comparing the numerous Scottish specimens collected by Mr. Judd with some typical forms of *T. bisuffarcinata* from the Korallen-Kalk of Muggendorf, recently sent to me by Dr. Sandberger, the identity of the Braamberry-Hill specimens became apparent.

In the same locality Mr. Judd obtained two internal casts, about an inch in length, of a well-characterized *Waldheimia*; but a further search for more specimens will be needed before attempting its specific identification.

Internal casts of a *Rhynchonella*, much approaching *R. pinguis*, Rœmer, have also been found in a light-yellow sandstone, slightly tinged with red, belonging to the Upper Oolite of Allt-na-Cuil, in Sutherlandshire; but as the Scottish Liassic and Oolitic Brachiopoda will, I hope, be fully treated in the forthcoming supplement to my monograph, it may be preferable to reserve all further details for that publication.

EXPLANATION OF PLATE VIII.

Figs. 1, 2.—*Rhynchonella Sutherlandi*, sp. n. Upper Oolite, Garty.
Figs. 3, 3*a*.—*Terebratula Jaossi*, sp. n. Upper Oolite, Garty.
Figs. 4, 4*b*.—*Terebratula humeralis*, Rœm. Upper Oolite, Garty.
Fig. 5.—*Terebratula bisuffarcinata*, Schl. Lower Calcareous Grit, Braamberry Hill.